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THE ECONOMIC CONSEQUENCES OF EURO-AREA MACRO-MODELLING
SHORTCUTS

by Libero Monteforte* and Stefano Siviero*

Abstract

Should euro-area economies be modelled in an aggregate (area-wide) fashion or in a disaggregate (multi-country) one? This paper tackles that question from both a statistical and an economic viewpoint. From a statistical viewpoint, aggregation bias criteria are found to signal that the degree of structural heterogeneity among euro-area economies is such that the loss of information entailed by an aggregate modelling approach may be far from trifling. From an economic viewpoint, we investigate the following issue: Are those statistically detectable asymmetries of any practical relevance when it comes to supporting monetary policy decision-making? To provide an answer to this question, we compute optimal monetary policy reaction functions on the basis of either an aggregate model or a disaggregate one, and compare the associated welfare losses. The results suggest that the welfare under-performance of an area-wide-model-based rule is not only non negligible, but also systematic, significant and robust with respect to a number of sensitivity analyses.

JEL classification: C53, E52; Keywords: euro area, aggregation, monetary policy rules, robustness.

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1. Introduction and main findings¹

Following the introduction of the single currency in a number of European countries on 1st January 1999, a number of novel challenges had to be faced by European policymakers, economic scholars and practitioners alike. Focussing on modelling challenges, monetary policymaking for the euro area as a whole clearly requires that policy analyses and projections, previously run on a country-by-country basis, be now extended to cover all economies in the area in a consistent way. This raises the following basic issue: should the Eurozone economy be modelled as if it was one single, large economy (area-wide, or aggregate, approach)? Or, alternatively, should disaggregate country data be used to build inter-linked single-country models (multi-country, or disaggregate, approach)?

In principle, aggregate models are sub-optimal whenever the individual units being aggregated display some degree of heterogeneity. Most empirical studies of the euro-area economy indicate that the extent of the divergences in the behaviour of the participating economies —particularly as far as the monetary transmission mechanisms is concerned— is far from being negligible: relevant asymmetries still exist, and they are likely to reflect deep structural differences.²

Despite the wealth of evidence on the heterogeneity of euro-area economies, few systematic efforts have been made to assess the statistical significance of that heterogeneity and to test whether the modelling of aggregate euro-area data —as opposed to individual country ones— is a sound econometric strategy. Furthermore, to our knowledge no attempt has been made to tackle that issue from a policymaking viewpoint.

¹ We thank participants in the CEPR-ZEI Conference “Empirical Models of the Euro Economy 2: Sectoral Aspects and Performance,” Bonn, 7-8 March 2003; participants in the Ecomod 2003 Conference, Istanbul, 3-5 July 2003; participants in the CFS Workshop “Empirical Methods for Building Macroeconomic Models,” Deutsche Bundesbank, Eltville, 11-18 August 2003; and participants in workshops at the Banque de France and University of Rome “La Sapienza” for many helpful comments and suggestions on previous versions of this work. The usual disclaimers apply. The views expressed in this paper are those of the authors and do necessarily represent those of the Bank of Italy.

² A (very) partial list of recent works that have a bearing on this issue includes Dornbusch, Favero and Giavazzi (1998), Ramaswamy and Sloek (1997), Guiso, Kashyap, Panetta and Terlizzese (1999), Hughes Hallett and Piscitelli (1999), Dedola and Lippi (2000), Clements, Kontolemis and Levy (2001), Ciccarelli and Rebucci (2002), and the papers presented at a recent ECB conference (“Monetary Policy Transmission in the Euro Area”, ECB, Frankfurt, 18-19 December 2001). Not much effort has yet been devoted to trying to identify the structural determinants underlying the observed asymmetries. Fragmentary evidence may be found in van Els, Locarno, Morgan and Villetelle (2001).

This paper tackles the aggregate/disaggregate euro-area modelling trade-off from both a statistical and an economic viewpoint.

From a statistical viewpoint, the greater parsimony and transparency of aggregate models usually comes at the cost of an aggregation bias. We therefore explore —using a number of criteria and diagnostics proposed in the literature— whether signs of aggregation bias may be detected in the estimates of a stylised model of the euro area, and assess the size of that bias. We find that the empirical evidence consistently supports the conclusion that ignoring the heterogeneity of euro-area countries entails a sizeable loss of information.

The core of the paper is the analysis of the aggregate/disaggregate trade-off from an economic viewpoint: we propose a model-selection-criterion that relies on economic arguments rather than statistical ones. We begin by observing that statistical evidence of aggregation bias cannot *per se* be taken to imply that the use of aggregate econometric tools would result in dramatically unreliable analyses and insight, and hence in markedly sub-optimal economic decisions. To explore whether or not that would be the case, we assess the performance of two hypothetical euro-area monetary policy-makers: the first relies on an aggregate model of the euro area, while the second takes her decisions on the basis of a disaggregate model. We then explore whether the performance of the former policy-maker would be perceivably worse than that of the latter. Our approach may thus be viewed as proposing a policy-based metric for assessing the economic relevance of structural asymmetries across euro-area economies.³ Should this analysis suggest that no big welfare losses are at stake, an area-wide modelling approach might remain the preferred option, regardless of what the standard statistical checks of aggregation bias may indicate. Our findings suggests that the additional welfare losses that would be incurred by relying on an aggregate modelling approach (as opposed to a disaggregate one) may be far from trifling. This conclusion, while obviously model-dependent, appears to be robust with respect to a number of sensitivity analyses.

A few papers have addressed the aggregate/disaggregate trade-off in the context of euro-area monetary policymaking from different angles: De Grauwe and Piskorski (2001) and Aksoy, De Grauwe and Dewachter (2002) investigate the implications of nationalistic

³ From the viewpoint of the debate on robust rules (see the contributions in Taylor (1999) and, more recently, Levin and Williams (2003)), the paper may be viewed as focussing on one particular type of robustness (i.e., robustness with respect to the assumption of aggregability).

attitude of the ECB Governing Council members, and assess how the performance of euro-area monetary policy is affected by changes in the definition of preferences (specifically, they contrast loss functions defined over area-wide aggregates and loss functions that are weighted averages of the individual national central banks' ones). Angelini, Del Giovane, Siviero and Terlizzese (2002) focus on the role that can be played by information at the national level in setting the single monetary policy of the euro area, under the maintained assumption that preferences are defined over area-wide aggregates. They find that, by reacting to national information, the euro-area central bank attains significant reductions in (aggregate) inflation and output variability, as opposed to the case in which the interest rate reacts to area-wide variables only. This paper may thus be viewed as filling a gap in the literature, by focussing on the implications of the aggregate/disaggregate trade-off on modelling-for-policy choices.

A question naturally arises here: Why there seems to be no comparable interest for aggregation issues in the case of other monetary unions? The answer rests, we feel, with the fact that heterogeneity among euro-area countries is widely presumed to be much more pronounced than in other monetary unions or federal states (the US being the most obvious comparison), largely because of differences in the institutional frameworks of participating countries, which are expected to persist, at least to a certain extent, for some time into the future. One is thus inclined to conjecture that the potential information loss associated with using aggregate econometric tools is likely to be larger for the euro area than for other economies.⁴

The paper is organized as follows. Section 2 shortly describes the two basic modelling options faced by euro-area modellers and presents and compares the main features of the stylised aggregate and disaggregate models used in the remainder of the paper. Section 3 briefly presents the results of a number of aggregation bias tests and criteria. Section 4 presents the approach followed to assess the economic relevance of structural heterogeneity across euro-area countries. Section 5 offers a quantification of the additional welfare losses that would be incurred if euro-area monetary policy was to rely on an aggregate model rather than a disaggregate one, and investigates the model and rule features that result in those additional losses. Section 6 provides an estimate of the significance of the additional losses and tests

⁴ However, significant regional differences in the transmission of monetary policy have been detected even in the case of the US economy; see Carlino and DeFina (1998, 1999) and Owayang and Wall (2003).

the robustness of the main results along various dimensions (how the results would likely be affected should euro-area economies tend to converge in the future? Would the conclusions be different if the competing rules were assumed to be forward-looking?). Section 6 concludes.

2. Aggregation bias testing in two simple models of the euro area

When it comes to building empirical tools for euro-area forecasting and policy analysis purposes, two basic options are available: as a first alternative, one could build a disaggregate, or multi-country, model, i.e., a model describing the functioning of the economic mechanisms in the individual countries of the area and the inter-linkages amongst them; in such a model, country-specific features may be reflected by either the structure of the model and/or the value of its parameters. As a second, much less onerous, alternative, one may first aggregate the individual country data⁵ and model the latter as if they referred to one single, large and homogeneous economy (aggregate, or area-wide, model).⁶

In this paragraph we describe the two (aggregate and disaggregate) simple AS-AD models used in the remainder of this paper and present their main properties. Several variants of models of the same kind as the ones we consider have been widely used in the literature on optimal policy rule; see Rudebusch and Svensson (1999) for a strictly backward-looking version and Clarida, Gali and Gertler (1999) for a fully forward-looking one. Both models presented below are purely backward-looking and are thus potentially affected by the issue of policy-dependent parameters (Lucas Critique).⁷ However, the issue we investigate is essentially an empirical one, and the European monetary policy-maker largely relies on models belonging to the same broad family as the ones we use here (see ECB (2001)), so that our rules are derived within a modelling framework similar to that underlying actual monetary policy

⁵ Labhard, Weeken and Westaway (2001) argue that the actual choice of the aggregating function is unlikely to affect the properties of the model in any significant way. The aggregating functions used in this paper are briefly described below.

⁶ Both approaches are being pursued in practice, even by the same institutions. For instance, the European Central Bank (ECB) maintains an aggregate model (see Fagan, Henry and Mestre (2001)) and is in the process of building a disaggregate one. Also, the euro-area projections by the Eurosystem (the institution comprising the ECB and the national central banks of euro-area countries) are the result of a multi-staged process that involves aggregating country-specific projections while also using information derived from the ECB's area-wide model, to come to one single, consistent picture (see ECB (2001)).

⁷ Lucas (1976). See, however, Sims (1982), Farmer (1991), Hendry (1988), Favero and Hendry (1992) and Altissimo, Siviero and Terlizzese (2002) for a number of arguments that mitigate the implications of the Lucas Critique.

decisions. Moreover, the empirical evidence presented below overwhelmingly supports the hypothesis of structural stability, even for the most recent period, when, arguably, a major shock occurred in the policy regime. Finally, using one of the models presented below, Angelini, Del Giovane, Siviero and Terlizzese (2002) show that the relevance of disaggregate information for euro-area monetary policymaking is robust with respect to the presence of forward-looking elements, as long as these are not dominant.

The Aggregate Euro Area Model (AEAM) is a simple two-equation model estimated using aggregate data for the three largest economies in the euro area (Germany, France and Italy, jointly accounting for over 70 per cent of the area GDP). It includes an aggregate supply equation (also referred to as Phillips curve) and an aggregate demand equation (also referred to as IS curve). The first equation determines inflation as a function of lagged inflation and the output gap; the sum of the coefficients on lagged inflation is constrained to unit (the restriction cannot be rejected), so that the Phillips curve is of the accelerationist type. The second equation relates the output gap to its own lagged values and the real interest rate.⁸

A general-to-specific modelling approach was followed in searching for a satisfactory empirical specification, starting with 6 lags for all variables on the right-hand-side of the two equations. The final specification is the following:

$$\begin{aligned}\pi_{t+1} &= \alpha_1 \pi_t + (1 - \alpha_1) \pi_{t-3} + \eta y_t + u_{t+1} \\ y_{t+1} &= \theta y_t + \psi(i_{t-1} - 4 \cdot \pi_{t-1}) + v_{t+1}\end{aligned}$$

where π_{t+1} is the quarter-on-quarter consumer inflation rate; y_{t+1} is the output gap; i_{t+1} is the short-term interest rate; $i_{t+1-k} - 4 \cdot \pi_{t+1-k} = r_{t+1}$ is a measure of the ex-post real interest rate.⁹

⁸ Neither equation includes foreign variables; in other words, the euro area is modelled as a closed economy, similarly to what is invariably done for the US. Note that the degree of openness of the euro area as a whole is similar to that of the US.

⁹ The source of data is the ESA-95 National Accounts for inflation and the output gap, and the BIS data-bank for the short-term interest rate. Inflation is measured by the quarter-on-quarter rate of change of the (seasonally adjusted) households' consumption deflator. Potential output was estimated by applying a band-pass filter (Baxter and King (1995)) to the (log) GDP, selecting frequency components of 32 quarters and higher, with a truncation of 16 quarters. National variables were aggregated using a fixed-weight procedure. For inflation, 1999 PPP consumer spending shares were used. For the output gap, the weights are given by 1999 PPP real GDP shares. For interest rates, the weights are the PPP nominal GDP shares computed by the OECD. The GDP and consumer spending weights are, respectively 0.43 and 0.44 for Germany, 0.29 and 0.27 for France, 0.28 and 0.29 for Italy.

The model was estimated with SURE, thus allowing for the possibility of correlation between the residuals of the two equations. The sample period extends from 1978.Q1 to 1998.Q4, totalling 84 quarterly observations. The estimation results are presented in Table 1.

The Disaggregate Euro Area Model (DEAM) includes, for each of the three largest euro-area countries, the same set of equations as the AEAM. The specification of both the aggregate supply and the aggregate demand equation is similar to the one adopted in the AEAM but, in addition, it allows for cross-country linkages. Specifically, in the AS equation inflation in any given country depends not only on its own lagged values and on the corresponding output gap, but also, at least in principle, on inflation “imported” from the other two countries (inflation imported from either country is given, in estimation, by the sum of inflation in that country and the rate of change of the relevant bilateral exchange rate). Analogously to the case of the AEAM, the sum of the coefficients on lagged and imported inflation is constrained to be 1 (the restriction is accepted by the data for all countries). Similarly, in the AD equation the output gap in any of the three countries depends on its own lagged values and on the corresponding real interest rate, as in the AEAM; in addition, it may react to the output gap in the other two countries, reflecting trade linkages.¹⁰

As the model set-up allows for instantaneous cross-country linkages, 3SLS were used to estimate its parameters. The sample period extends from 1978.Q1 to 1998.Q4, as for the AEAM. For most of the sample period, the exchange rates among Germany, France and Italy, though constrained by the ERM of the EMS, were not fixed; lagged values of all variables included in the model were used as instruments for the exchange rates.¹¹ As to interest rates, we assume that they affect the output gap only with a lag (which, incidentally, is consistent with most empirical evidence): 3SLS estimation could hence be carried out without augmenting the estimated model with interest rate reaction functions for the three countries.

¹⁰ Real exchange rate terms were found to be non significant and were dropped in the final specification.

¹¹ In the experiments presented below, the percentage change of the exchange rate was set identically equal to zero, consistently with the introduction of the single currency as of January 1, 1999.

The general form of the two-equation sub-model for country j is the following:¹²

$$\begin{aligned}\pi_{t+1}^j &= \sum_{k=1}^p \alpha_{j,k} \pi_{t+1-k}^j + \sum_{i \neq j} \sum_{k=0}^p \beta_{j,i,k} (\pi_{t+1-k}^i + \dot{e}_{t+1-k}^{i,j}) + \sum_{k=0}^p \eta_{j,k} y_{t+1-k}^j + u_{t+1}^j \\ y_{t+1}^j &= \sum_{k=1}^p \theta_{j,k} y_{t+1-k}^j + \sum_{i \neq j} \sum_{k=0}^p \varphi_{j,i,k} y_{t+1-k}^i + \sum_{k=1}^p \psi_{j,k} (i_{t+1-k}^j - 4 \cdot \pi_{t+1-k}^j) + v_{t+1}^j\end{aligned}$$

where: $J = G, F, I$ denotes country variables and $\dot{e}_{t+1-k}^{i,j}$ is the quarter-on-quarter rate of change of the exchange rate between country i and country j (units of country j 's currency for 1 unit of country i 's currency).

The starting specification included on the right-hand-side of each estimated equation the first 6 lags of all relevant variables. Joint estimation of the three sub-models resulted, after dropping all insignificant lags, in a much more parsimonious specification (see Table 2, where the exchange rates have been omitted, as they play no role in the version of the model used in Section 4 to identify optimal policy rules).

Both models were re-estimated with data up to 1996.Q4, so as to make a reasonably sized sample (20 quarterly observations, from 1997.Q1 to 2001.Q4) available for stability testing. The resulting parameter estimates are virtually unchanged with respect to those found with the original sample. For both models, the empirical evidence overwhelmingly rejects the hypothesis of parameter instability (the tail probability of the relative F-test is always larger than 50 per cent). Interestingly, the cross-country dispersion of all DEAM parameters but one is actually slightly higher with the full sample estimates.

The impulse responses of both models —obtained by simulating the AEAM and DEAM augmented with the same Taylor-type stabilizing policy rule; see Monteforte and Siviero (2003)— are broadly in line with well-established stylized facts about the euro-area economy.¹³ In particular: (i) any shock tends to result in remarkably persistent deviations from the

¹² In keeping with the approach followed in similar literature, neither the AEAM nor the DEAM that we use for our experiments below include any constant terms, i.e., it may be taken to provide a description of the functioning of the euro area economy in the neighborhood of equilibrium. This amounts to implicitly assuming that the same equilibrium values apply to all countries, a condition that does not necessarily hold in the sample period, particularly regarding the (implied) equilibrium real interest rates.

¹³ See, e.g., the evidence presented at the Conference “Monetary Policy Transmission in the Euro Area”, ECB, Frankfurt, 18-19 December 2001.

equilibrium; (ii) a monetary policy shock initially affects output more than inflation; (iii) the full response of output and inflation to an interest rate shock takes some time to materialize.

The general pattern of most impulse responses is similar in the two models. However, a few relevant differences are apparent: (i) deviations from the equilibrium tend to be more pronounced and persistent in the DEAM; (ii) while the maximum effect on output occurs, in both models, about one year after the shock, the maximum effect of inflation is somewhat delayed in the DEAM; (iii) the effects of monetary policy on inflation are stronger in the DEAM, while the opposite holds for the output gap; (iv) because of the generally more pronounced impact of aggregate supply and aggregate demand shocks in the DEAM, monetary policy tends to be more activist than in the AEAM, even if both models are augmented with exactly the same Taylor-type rule.

Finally, there is some indirect evidence supporting the conjecture that the results presented in this paper would likely be broadly confirmed if similar analyses were performed with some of the main models of the euro area developed and maintained by policymaking and economic analysis institutions.¹⁴ First, virtually all models in use with other institutions signal the existence of a significant degree of heterogeneity among the three largest economies in the euro area; this is crucial for our argument, as lack of heterogeneity would by definition entail that there is no value added in using a disaggregate model instead of an aggregate one. Second, the differences in the features of the DEAM and AEAM as highlighted by the analysis of impulse responses above are remarkably similar to the differences found when the IMF's Multimod Mark III (disaggregate) model is compared with its aggregate version (Mark IIIb).¹⁵ For instance, both comparisons indicate that the effects of a monetary policy shock on output are initially stronger in the aggregate models (AEAM and Mark III) than in the corresponding disaggregate ones (DEAM and Mark IIIb); by contrast, the effects on inflation are sensibly more pronounced in the disaggregate models than in the aggregate ones. Discounting for the differences in the experimental design, even the size of the differences between the reaction of the AEAM and that of the DEAM is similar to what one finds when the Mark IIIb and Mark III

¹⁴ Specifically, Monteforte and Siviero (2003) consider the following models: the ECB's Area Wide Model (Fagan, Henry and Mestre (2001); Dieppe and Henry (2002)); the IMF's Mark III (disaggregate) and Mark IIIb (aggregate) (Hunt and Laxton (2002)); the European Commission's Quest (Roeger and in't Veld (2002)); the National Institute's NiGem (Barrell, Gottschalk, Hurst and Welsch (2002)).

¹⁵ The IMF models largely share the theoretical underpinnings and empirical modelling approach, so that any differences between them may be interpreted as largely stemming from what the data themselves indicate.

models are compared. The salient features that emerge from the comparison of our aggregate and disaggregate models are thus confirmed if other modelling set-ups are examined.

3. Direct aggregation bias investigation

Analysis of aggregation bias dates back to Theil's seminal work of 1954. In that set-up, the aggregation bias vanishes, under the assumption that both the aggregate and disaggregate equations are correctly specified, in only two cases: (i) micro homogeneity (i.e., when the parameters of any disaggregate equation are identical to those of any other); (ii) compositional stability (i.e., when the ratio between each disaggregate exogenous variable and the corresponding aggregate one is constant over time). If none of those two conditions hold, the aggregate relationship will have an additional error component as compared with the disaggregate ones; such additional components is what Theil (1954) labelled "aggregation bias".

The most natural criterion to assess the relevance of the aggregation bias consists of comparing the sum of squared residuals associated with the disaggregate equations with that of the aggregate one, as first proposed by Grunfeld and Griliches (1960). Pesaran, Pierse and Kumar (1989) proposed a slightly different criterion, which corrects for small sample bias in the sum of square residuals. The criterion consists of comparing the aggregate and (modified) disaggregate standard errors.¹⁶ If the micro equations are correctly specified, the latter is necessarily smaller than or at most equal to the former by construction. However, the opposite may well happen in practice if the equations that are compared are affected by misspecification errors.

Monteforte (2003) developed an Factor-Analysis-based approach for aggregation bias testing. In short, that approach rests on identifying the idiosyncratic components of the micro equations: intuitively, the larger those components, the less appropriate the assumption of aggregability.

¹⁶ In addition to proposing the criterion presented in the text, Pesaran, Pierse and Kumar (1989) also derived a formal test for aggregation bias. A drawback of that test is that it may be computed only when the number of micro units is relatively large (this condition is not satisfied in the empirical application of this paper).

Finally, Zellner and Tobias (2000) and Baltagi, Griffin and Xiong (2000) have advocated assessing the relevance of the aggregation bias on the basis of the relative forecast performance of the aggregate and disaggregate models.

In the case at hand, all those criteria and tests consistently point in the direction of rejecting the hypothesis of no aggregation bias.

Grunfeld and Griliches's (1960) and Pesaran, Pierse and Kumar's (1989) criteria for the AEAM and DEAM are shown in Table 3. Clear signs of aggregation bias emerge on the basis of both criteria, particularly in the case of the aggregate supply (Phillips Curve) equations. Analogous indications are provided by the criteria based on factor models (Table 4): the idiosyncratic components of the disaggregate equations are far from trifling. Finally, the results displayed in Table 5 shows that the hypothesis that the DEAM forecast-encompasses the AEAM cannot be rejected in the case of the Phillips Curve equations, while the results are mixed for the aggregate demand equations (Table 5).

Our results are consistent with those of Mayes and Virén (2000), who find that asymmetries across euro-area aggregate supply curves are very pronounced; Fabiani and Morgan (2003) also find some evidence of asymmetry of Phillips curves. By contrast, Fagan and Henry (1999) find that the aggregate euro area money demand equation is basically unaffected by aggregation bias.

To sum up, all available evidence indicates —although with different degrees of “sharpness”— that the hypothesis of no aggregation bias cannot be accepted, especially in the case of the aggregate supply equations.

4. Indirect aggregation bias investigation: Design of experiment

In the light of the results of the previous section, a disaggregate modelling approach of the euro area appears to be statistically sounder than its alternative. It remains to be ascertained whether it is also preferable from an economic viewpoint. To do this, we compare the performance of two hypothetical European monetary policy-makers. The first policy-maker is assumed to react to the state of the economy as represented by the AEAM; by contrast, the second policy-maker's optimal reaction is computed on the basis of the DEAM.

Since the vector of state variables is different for the two models, the corresponding optimal instrument rules (i.e., rules that exploit all the information provided by the whole set of state variables, which we label FO rules) would not be easily comparable. We thus impose that both rules belong to the Taylor-type family (i.e., the arguments of both rules are the current area-wide inflation and output gap and the lagged value of the policy instrument only); for the sake of making the comparison as fair as possible, we further require that the DEAM-based rule (henceforth, DEAMBR) only respond to area-wide aggregates, as is necessarily the case for the AEAM-based rule (AEAMBR).¹⁷

A standard time-separable quadratic loss function is assumed, its arguments being the euro area average inflation rate and output gap, and a term that attaches a cost to the volatility of the policy instrument; i.e.:

$$(1) \quad L_t = E_t \sum_{\tau=0}^{\infty} \delta^{\tau} [\bar{\pi}_{t+\tau}^2 + \lambda \cdot y_{t+\tau}^2 + \mu \cdot (\Delta i_{t+\tau})^2]$$

where δ is a discount factor, and λ and μ are parameters that reflect the policy-maker's preferences; $\bar{\pi}_t$ is the (euro-area average) year-on-year consumer inflation rate (i.e., $\bar{\pi}_t = \pi_t + \pi_{t-1} + \pi_{t-2} + \pi_{t-3}$). Note that eq. (1) implies that the euro-area policy-maker is only interested in euro-area average outcomes, in line with the official Eurosystem's view of the monetary policy objective and strategy.

For $\delta \rightarrow 1$ the sum in eq. (1) may be interpreted as the unconditional mean of the period loss function (see, e.g., Rudebusch and Svensson (1999)), which is given by the weighted sum of the unconditional variances of the target variables:

$$(2) \quad L_t = \text{var}[\bar{\pi}_t] + \lambda \cdot \text{var}[y_t] + \mu \cdot \text{var}[\Delta i_t]$$

In the following we adopt the loss function defined as in eq.(2). The search for optimal policy was repeated with a wide range of values for λ and μ , ranging from a case in which the monetary policy-maker is only interested in inflation ($\lambda = \mu = 0$) to the opposite extreme, in which the policy-maker attaches a comparatively very high cost to deviations of the output

¹⁷ The performance of rules that allow the policy-maker to respond to country-specific variables is investigated in Angelini, Del Giovane, Siviero and Terlizzese (2002).

gap from its equilibrium value (zero) and to the volatility of the policy-controlled interest rate ($\lambda = 5, \mu = 3$).¹⁸

The two competing rules may thus be synthetically described as follows:

AEAMBR

$$\min_{\gamma_1^A, \gamma_2^A, \gamma_3^A} E_t \sum_{\tau=0}^{\infty} L_{t+\tau} = \min_{\gamma_1^A, \gamma_2^A, \gamma_3^A} E_t \sum_{\tau=0}^{\infty} [\bar{\pi}_{t+\tau}^2 + \lambda \cdot y_{t+\tau}^2 + \mu \cdot (\Delta i_{t+\tau})^2]$$

s.to: • AEAM (see Section 2)
 • $i_t = \gamma_1^A \cdot \bar{\pi}_t + \gamma_2^A \cdot y_t + \gamma_3^A \cdot i_{t-1}$

and:

DEAMBR

$$\min_{\gamma_1^M, \gamma_2^M, \gamma_3^M} E_t \sum_{\tau=0}^{\infty} L_{t+\tau} = \min_{\gamma_1^M, \gamma_2^M, \gamma_3^M} E_t \sum_{\tau=0}^{\infty} [\bar{\pi}_{t+\tau}^2 + \lambda \cdot y_{t+\tau}^2 + \mu \cdot (\Delta i_{t+\tau})^2]$$

s.to: • DEAM (see Section 2)
 • $i_t = \gamma_1^M \cdot \bar{\pi}_t + \gamma_2^M \cdot y_t + \gamma_3^M \cdot i_{t-1}$

Let us now tackle the crucial issue of how the performance of these two rules may be compared. The statistical evidence presented in Section 3 clearly indicates that the DEAM provides a more reliable description of the functioning of the euro-area economy than the AEAM. Accordingly, we assess, using the DEAM and the corresponding variance-covariance matrix of residuals, the welfare function values associated with the optimised AEAM-based and DEAMBRs computed as described above.

Given the way in which the two rules are compared, it is obviously the case that the AEAMBR cannot outperform the DEAMBR by construction. However, the under-performance of the AEAM could well be trifling. Our results below, by contrast, suggest that the “welfare distance” between the two rules is non-negligible, and that it is significant. Also, robustness checks are presented in Section 6 that investigate how the main results change if the assumption that the DEAM provides a fully reliable description of the euro-area economy is relaxed.

¹⁸ The ranges chosen for the loss function parameters are similar to the ones typically assumed in the literature; see, e.g., the papers collected in Taylor (1999).

As a benchmark, we also compute, on the basis of the DEAM, the FO rule and the associated optimised target variances and welfare loss.¹⁹ This third set of results is used to compare the gains attainable with the DEAMBR with the (larger) ones that could be achieved by relying on the rule that, by definition, performs best within the DEAM.

5. Main results

The main results of our experiments are shown in Figures 1 and 2 and Table 6. Let us focus first on the outcomes of the two competing rules (Figure 1). The top chart of the figure reports the percentage increase in the optimized value of the objective function if the AEAMBR is followed instead of the DEAM-based one. The welfare losses are far from negligible, being smallest (10 per cent) in the neighborhood of pure inflation targeting, excluding, however, the latter case: in the case of pure inflation targeting, the AEAMBR does not actually succeed in stabilizing the DEAM, thus resulting in an explosive unconditional variance-covariance matrix, so that the welfare loss due to following the AEAMBR is in principle infinite. The loss is consistently large if the weight of interest rate smoothing in the loss function is zero, and exceeds 20 per cent if the weights of either the output gap or the volatility of the policy instrument are relatively high. The key message given by the figure is that ignoring the structural differences among the euro area economies, and so adopting a model that treats them as a single and homogeneous “whole,” tends to lead to a sizeable worsening of the performance of monetary policy, particularly if the policy-maker only cares about inflation.

The bottom chart of Figure 1 reports the same results in relative terms, using the FO rule as a benchmark;²⁰ the chart suggests that an hypothetical policy-maker relying on the AEAM would go a long way towards further worsening the distance (measured in terms of welfare) between the DEAM-based and the FO rules. In particular, for $\mu = 0$ the AEAMBR implies an additional loss comprised between almost 25 and over 50 per cent of the loss that is incurred if the DEAM-based, rather than the FO, rule is followed. Thus, not only is the size of the gains

¹⁹ For this purpose, we first derive the state-space representation of the DEAM, and then solve a standard stochastic linear regulator problem (see Chow (1970), Sargent (1987), and, for an application to the issue of optimal monetary policy design, Rudebusch and Svensson (1999)).

²⁰ The FO rule differs from either of the other two, in that the arguments of the rule are the current and lagged quarter-on-quarter country-specific inflation rates, rather than the average year-on-year inflation rates.

that can be attained with a multi-country modelling approach not negligible, but, adopting the true optimum rule as a benchmark, those gains are considerable.

The results can be assessed directly in terms of the optimised unconditional standard deviations of inflation, the output gap and interest rate changes. This is done in Figure 2, showing the optimal inflation/output gap frontier (in terms of optimized standard deviations of those variables) for the AEAM-based, DEAM-based and FO rules. The frontiers have been computed, for given μ , by letting λ take a grid of values between 0 (north-west) and 5 (south-east). While the frontier associated with the FO rule is positioned considerably to the south-west with respect to the frontier associated with the DEAMBR, the latter consistently attains a combination of inflation and output gap volatility that is much better than that of the AEAMBR.

Can one trace these outcomes back to the properties of the different optimal rules, and in particular to the optimised parameters on inflation, the output gap and the lagged interest rate in the monetary policy reaction functions? A selection of the latter are presented in Table 6.²¹ At least one feature is noteworthy in that table: the AEAMBR is consistently not “reactive” enough to either inflation or the output gap compared with the other two rules.

Further insight on the nature of the two rules is provided by “Fault tolerance analysis,” as proposed by Levin and Williams (2003). Figure 3 shows the increase in the welfare loss that arises as the parameters of the policy rules move away from the optimal ones. The results suggest that the degrees of fault tolerance of the two rules are not markedly dissimilar, although the DEAMBR is somewhat more tolerant. By contrast, the results are heavily affected by the loss function weights: specifically, the degree of fault tolerance declines sharply, for all rules and for all parameters, as the weights of the output gap and the interest rate volatility increase.

²¹ Since the arguments of the FO rule are the quarter-on-quarter inflation rates, as opposed to the year-on-year inflation rates of the AEAM- and DEAM-based rules, the latter were re-computed, for the purpose of compiling Table 6, under the assumption that the policy rate reacts to quarterly inflation and aims at stabilizing annualised quarter-on-quarter inflation. Thus, the FO, AEAM-based and DEAM-based rules reported in Table 6 are fully comparable. Also note that the FO rule depends on the complete set of the 15 state variables in the DEAM: the latter set comprises inflation and output gap in the various countries for different lags. For ease of comparison, the coefficient on inflation reported in Table 6 is given, for the FO rule, by the sum of the value of all coefficients that the rule assigns to inflation in all countries and for all lags; similarly for the output gap.

6. Robustness checks

The results above suggest that the under-performance of the rule that relies on the aggregate model are *prima-facie* far from trifling. We now investigate whether those results are also significant; we also examine what would be the consequences of structural convergence of euro area economies; finally, we consider the possibility that the rules be forward-looking.

To test whether the welfare distance between the two rules is significant (which, as far as we know, has never been addressed in the literature on optimal monetary rules), we perform two stochastic simulation exercises.

The first exercise consists of extracting 1,000 replications from the set of estimated residuals and simulating the DEAM, for each replication, under either one or the other of the two competing rules.²² The results show that the DEAMBR delivers a better outcome than the alternative in the overwhelming majority of replications (always at least 80 per cent; see the top chart of Figure 4). Hence, not only is the gain large on average, but is also systematic. We also formally tested the hypothesis that the average welfare loss associated with following the DEAMBR is lower than the average loss with the AEAMBR.²³ The results are overwhelmingly supportive of the hypothesis: for all combinations of policy parameters the tail probability of the test is virtually zero (the values of the test for all λ 's and μ 's are shown in the bottom chart of Figure 4, together with the 1 per cent critical value).

The second exercise explicitly accounts for the stochastic nature of the estimated coefficients. In the previous section, the DEAM was assumed to describe accurately the functioning of the economy; the stochastic nature of the estimated parameters was thus ignored. Actually, the most one could argue is that with a certain probability the “true” model parameters lie in the neighborhood of the estimated ones. We mean to investigate whether our main results are robust with respect to relaxing the assumption that the data generating process and the DEAM coincide. The need for such a check is particularly acute

²² Each replication includes 800 realizations of the shocks for the six stochastic equations in the model, one realization per period. Only the last 400 simulated values are used to evaluate the objective function, to prevent the results from being biased by the initial conditions. A different experiment could consist of sampling from the error distribution, re-estimating the two models for each replication, and re-computing the rules each time. Such an experiment, however, would by construction result in an under-performing AEAM-based rule for each and any replication, which is not necessarily the case here.

²³ The test is the standard one-sided test for the equality of the means of normally distributed variables.

in the case at hand, because of the way in which we compare the performance of the DEAM-based and AEAMBRs. To account for the variability of the estimated coefficients we extract 5,000 replications from the empirical distribution of the estimated DEAM coefficients and, without re-computing the DEAM-based and AEAMBRs, we compute, for each replication of the model coefficients, the associated loss function. We then examine the distribution of the loss function under the two rules.

The results are shown in Figure 5. The top chart indicates that in (almost) 70 to 80 per cent of all the “alternative worlds” that are plausible (i.e., within the confidence interval) given the estimate of the DEAM, the DEAMBR does strictly better than the AEAMBR for any combination of the preference parameters. Hence, coefficient variability is not such as to jeopardize our conclusions above. Furthermore, for a large percentage of replications, the reduction of the loss function delivered by the DEAMBR is sizeable (see Monteforte and Siviero (2003) for details). Finally, as in the exercise above, we formally test the hypothesis that the average (across replications) welfare loss associated with the DEAMBR is lower than the average loss obtainable with the AEAMBR (the resulting tail probabilities are shown in the bottom chart of Figure 5). With a confidence level of 5 per cent, only for 2 combinations of the preference parameters (less than 3 per cent of the cases) one is not able to accept the null hypothesis (and even then is the rejection only marginal). For most combinations of preference parameters (62 out of 77, i.e., over 80 per cent) the null hypothesis cannot be rejected at the confidence level of 1 per cent.

Overall, these results clearly indicate that the DEAMBR tends to perform significantly better than the AEAM-based alternative, provided that our multi-country model is a reasonable approximation of the data generating process, or at least a more reasonable one than the AEAM. Not only is the welfare loss associated with the AEAMBR large, but it is also statistically significant and generally “robust” to parameter uncertainty.

But what could happen in the far future? There is no reason why convergence should necessarily take place;²⁴ moreover, there is no compelling evidence that much convergence has taken place in the long run-up to the euro area,²⁵ and the evidence presented in Section

²⁴ Hughes Hallet and Piscitelli (2002a) show that integration may or may not imply convergence, a key factor in determining the result being the size of the economies involved.

²⁵ Eichengreen (1997) and Demertzis and Hughes Hallett (1998), have tackled the issue of the symmetry of

2 shows no signs of instability in the DEAM and AEAM after the introduction of the single currency. Moreover, the welfare distance between the two rules (both of which are computed using models estimated with pre-euro data) remains significant even if the comparison only focusses on the early stages of the euro era (see Monteforte and Siviero (2003) for details).

However, it may be informative to explore how the comparison between the AEAMBR and DEAMBR would be affected were more symmetry of stochastic disturbances to prevail among the euro area countries than detected in the past.²⁶ We thus assume that some sort of convergence in the stochastic processes that generate the disturbances of the DEAM will occur in the future. Specifically, we assume that countries that become more intimately tied to one another will tend to share the same shocks, and that the underlying country-specific stochastic processes will influence those common shocks proportionately to the country's relative size (the largest country exerting a comparatively stronger effect on the common shocks than the other two, and so on). More in detail, we take full convergence of aggregate demand shocks to mean that the disturbances in the aggregate demand equation become exactly the same in all countries. As in De Grauwe and Piskorski (2001), we assume that, once full convergence has been reached, the common variance (as well as covariances) is given by the square of a weighted average of the historical estimated standard deviations:

$$(3) \quad \sigma_{y|FC}^2 = (\omega_{yG}\sigma_{yG} + \omega_{yF}\sigma_{yF} + \omega_{yI}\sigma_{yI})^2$$

where $\sigma_{y|FC}^2$ denotes the variance of the common AD shock under convergence; σ_{yG} , σ_{yF} , σ_{yI} are the estimated standard deviation of AD disturbances in the three countries; ω_{yG} , ω_{yF} , ω_{yI} are the GDP weights of the three countries.

We also consider the possibility of partial convergence, which we assume to be parameterized by ξ_{AD} , ranging from 0 (no convergence) to 1 (full convergence). For any given choice of the ξ_{AD} parameter, the corresponding elements of the variance-covariance matrix of

the shocks to the European economies, or lack thereof; their empirical evidence shows that, although the European economies have followed rather similar policies in recent years, there is little evidence of a strengthening of the degree of symmetry of the disturbances affecting the various economies.

²⁶ In the following we focus only on the consequences of asymmetry in disturbances. As to asymmetry in behavioral parameters, Hughes Hallett and Piscitelli (2002b) find that they are likely to destabilize the business cycle in a way that is not wholly compensated by the existing constraints to national fiscal policies.

the disturbances are given by:

$$(4) \quad \sigma_{y_i|PC}^2 = \xi_{AD}\sigma_{y|FC}^2 + (1 - \xi_{AD})\sigma_{y_i}^2$$

$$(5) \quad \sigma_{y_j y_i|PC} = \xi_{AD}\sigma_{y_i|PC}\sigma_{y_j|PC}$$

for all i, j , so that the correlation of shocks among countries is given by ξ_{AD} itself.²⁷

Full and partial convergence of aggregate supply disturbances are defined in a similar way, with the convergence process now parameterized by ξ_{AS} .

Turning to the results, under the extreme assumption that there are only two stochastic processes in the euro area, the under-performance of the AEAMBR is considerably attenuated. Figure 6 reports, for the case $\lambda = \mu = 1$ (the results are similar for all other values of the policy parameter), the additional welfare loss entailed by adopting the AEAMBR rather than the DEAMBR, as the degree of similarity of supply- and demand-side shocks across countries increases (in the figure, the no-convergence loss found in Section 5 is set equal to 100).²⁸ With full convergence of shocks, there remains virtually no scope at all for using the DEAMBR, as expected. Note, however, that a relatively high degree of (uniform) convergence is needed before the loss associated with using the AEAMBR becomes relatively small. Examining what happens if the pace of convergence differs on the supply- and demand-sides (i.e., looking at the off-diagonal elements in the figure), one concludes that demand-side convergence without supply-side convergence would not be very effective in reducing the additional welfare loss associated with the AEAMBR. By contrast, even a limited degree of supply-side convergence would go a long way toward making the aggregation bias issue virtually irrelevant from a policymaking viewpoint. Whether these features are empirically robust seem worth investigating further in future work.

²⁷ It would, of course, be possible to introduce the further complication that the speed of convergence is not the same for all countries. For the sake of simplicity we ignore that possibility. Let us just remark that our concept of partial convergence tends to make cross-country heterogeneity disappear more smoothly than it would be conceivably possible.

²⁸ Both rules perform less satisfactorily than in the set of experiments where the historical variance-covariance matrix was assumed to hold, the worsening being, in general, more pronounced for the DEAM-based rule (and for the optimal instrument one) than for the AEAM-based rule. A general worsening of the optimized losses should indeed be expected: in the latter experiment the shocks are perfectly correlated, while the historical ones are virtually independent, and hence do not tend to reinforce each other.

Finally, we investigated whether our results would be any different if forward-looking AEAM- and DEAM-based rules were compared. Following Batini and Haldane (1999), we require the policy-controlled interest rate to react to model-consistent projections of future area-wide inflation and output gap, with the degree of forward-lookingness varying between 1 and 4. The results are not such as to modify the main message of our experiments: if inflation and the output gap enter the policy reaction function with a 1-period lead, the additional losses associated with using the AEAMBR draw a picture similar to Figure 1 above; the average loss is just marginally scaled down. With leads larger than 1, the additional losses actually tend to increase.

7. Concluding remarks: What implications for euro area econometric modelling?

The results presented in this paper suggest that heterogeneity in the economic structures of the countries participating in the euro area is not only statistically detectable but, perhaps more importantly, economically relevant. Specifically, monetary policy in the euro area is likely to be more effective if the econometric tools used to support monetary policy decision-making are disaggregate, rather than aggregate.

The welfare losses associated with an aggregate-model-based rule are not only sizeable but also highly significant.²⁹ Moreover, our results are generally robust with respect to model parameter variability. Finally, while our investigation of possible instabilities of the model in the most recent past does not suggest that euro area economies are becoming increasingly similar to one another, we nevertheless probe what could happen if convergence occurred in the future. We find that sizeable convergence has to occur before our conclusions no longer apply.

Our conclusions are apparent in our simplified model for the three main countries. Arguably they would be all the more supported if individual country models were to pay closer attention to country-specific institutional features, labor market arrangements, tax structures, etc., thereby presumably resulting in a more pronounced degree of asymmetry across models.

²⁹ Moreover, according to Angelini, Del Giovane, Siviero and Terlizzese (2002), the optimized value of the loss function could be further reduced if the single monetary policy were to exploit fully the available national information (by not simply relying on a DEAM, but also reacting to national information). Combining these results with ours, one can appreciate the full distance between a “pure aggregate approach” (using an AEAM to computing the monetary policy rule) and a “full multi-country one” (using a DEAM and allowing for the policy instrument to react to country-specific variable): the total reduction in the optimized value of the loss function is always in the neighborhood of 50 per cent or more.

Moreover, the odds would turn even more unfavourable to the aggregate modelling if the possibility that the models be nonlinear was taken into account.³⁰ In light of these remarks, it seems legitimate to conjecture that the reduction in the welfare losses that we measure is likely to provide a lower bound estimate.

Our results make a clear case for relying on a multi-country modelling approach when offering advice in support of the single monetary policy, and suggest that a line of research worth pursuing is a systematic investigation of the aggregation bias (both its size and its nature) that is likely to affect aggregate (area-wide) estimated relationships and their effects on optimal policies.

³⁰ See Hughes Hallett (2000).

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Table 1

ESTIMATE OF THE AEAM

| Input from: | Equation for: | |
|-------------|---|-----------------------|
| | π | y |
| π | 0.652 [-1] (0.075) 0.348 [-4] (restr.) | |
| y | 0.088 [-1] (0.035) | 0.769 [-1] (0.060) |
| r | | -.050 [-2] (0.022) |
| R^2 | 0.874 | 0.715 |
| \bar{R}^2 | 0.869 | 0.704 |
| σ | 0.286 | 0.487 |
| DW | 2.209 | 1.800 |

In parentheses: standard error of the coefficients.

In brackets: lag with which the variables enter the equations.

Table 2

| ESTIMATE OF THE DEAM | | | | | | | |
|----------------------|-------------|--|------------------------|--|------------------------|-----------------------|------------------------|
| | | Equations for: Germany | | Equations for: France | | Equations for: Italy | |
| Input from: | | π | y | π | y | π | y |
| Germany | π | 0.292 [-1] (0.089) 0.600 [-4] (0.069) | | 0.063 [0] (restr.) | | 0.036 [0] (restr.) | |
| | y | 0.095 [-1] (0.036) | 0.785 [-1] (0.062) | | | | 0.173 [0] (0.058) |
| | r | | -0.073 [-2] (0.038) | | | | |
| France | π | 0.108 [0] (restr.) | | 0.937 [-1] (0.044) | | | |
| | y | | | 0.022 [-2] (0.012) 0.022 [-3] (0.012) 0.022 [-4] (0.012) 0.022 [-5] (0.012) | 0.838 [-1] (0.052) | | |
| | r | | | | -0.036 [-2] (0.015) | | |
| | | | | | | | |
| Italy | π | | | | | 0.964 [-1] (0.010) | |
| | y | | | | | 0.064 [0] (0.028) | 0.657 [-1] (0.061) |
| | r | | | | | | -0.038 [-1] (0.016) |
| | R^2 | 0.514 | 0.635 | 0.902 | 0.730 | 0.960 | 0.752 |
| | \bar{R}^2 | 0.483 | 0.622 | 0.894 | 0.720 | 0.958 | 0.740 |
| | σ | 0.411 | 0.799 | 0.332 | 0.443 | 0.259 | 0.490 |
| | DW | 2.160 | 2.059 | 2.050 | 1.888 | 2.024 | 1.815 |

In parentheses: standard error of the coefficients.

In brackets: lag with which the variables enter the equations.

Table 3

AGGREGATION CRITERIA

| | <i>DEAM</i> | <i>AEAM</i> |
|------------------|-------------|-------------|
| AGGREGATE SUPPLY | | |
| GG criterium | 3.856 | 6.523 |
| PPK criterium | 0.225 | 0.286 |
| | | |
| AGGREGATE DEMAND | | |
| GG criterium | 15.948 | 18.961 |
| PPK criterium | 0.449 | 0.487 |

GG : Grunfeld and Griliches (1960)

PPK: Pesaran, H.M., R. G. Pierse and M.S. Kumar (1989).

Table 4

IDIOSYNCRATIC COMPONENTS OF MODEL REGRESSORS

(percentage of the standard deviation explained
by the idiosyncratic components across countries)

| Country | Output Gap | Interest Rates |
|---------|------------|----------------|
| Germany | 75.7 | 91.2 |
| France | 77.2 | 52.7 |
| Italy | 40.7 | 32.0 |

Note: The factor models have one common component specified as AR(2) in the case of the output gap and AR(1) for the interest rates. The estimation algorithm is Kalman filter, solved with Berndt, Hall, Hall, and Hausman (BHHH) optimization method; starting conditions for the AR coefficients in the common components are imposed to be equal to the OLS estimation of AR models.

Table 5

FORECAST ENCOMPASSING TEST REGRESSIONS

| Aggregate supply | Step ahead of the prediction (quarters) | | | | |
|---|---|------------------|------------------|------------------|------------------|
| | π_1 | π_2 | π_3 | π_4 | π_8 |
| <i>cost</i> | 0.027 (0.048) | 0.057 (0.070) | 0.068 (0.083) | 0.099 (0.093) | 0.211 (0.127) |
| <i>S_AEAM</i> | 0.095 (0.109) | 0.169 (0.159) | 0.113 (0.164) | 0.200 (0.234) | 0.158 (0.347) |
| <i>S_DEAM</i> | 0.887 (0.119) | 0.792 (0.185) | 0.841 (0.203) | 0.731 (0.294) | 0.658 (0.431) |
| \bar{R}^2 | 0.92 | 0.88 | 0.85 | 0.81 | 0.63 |
| <i>AEAM encompass*</i> | | | | | |
| <i>F – statistic</i> <i>p–value%</i> | 32.46 0 | 12.17 0 | 13.89 0 | 7.07 0 | 4.87 0.3 |
| <i>DEAM encompass**</i> | | | | | |
| <i>F – statistic</i> <i>p–value%</i> | 0.51 67.7 | 0.67 57.0 | 0.45 72.0 | 0.71 54.9 | 0.92 43.3 |

| Aggregate demand | Step ahead of the prediction (quarters) | | | | |
|---|---|-------------------|-------------------|-------------------|-------------------|
| | y_1 | y_2 | y_3 | y_4 | y_8 |
| <i>cost</i> | −0.016 (0.053) | −0.025 (0.090) | −0.022 (0.120) | −0.006 (0.141) | 0.015 (0.170) |
| <i>S_AEAM</i> | 0.244 (0.423) | 0.088 (0.567) | 0.143 (0.715) | 0.369 (0.811) | 0.852 (0.746) |
| <i>S_DEAM</i> | 0.767 (0.418) | 0.929 (0.562) | 0.853 (0.754) | 0.502 (0.918) | −0.310 (0.924) |
| \bar{R}^2 | 0.72 | 0.52 | 0.39 | 0.26 | 0.12 |
| <i>AEAM encompass*</i> | | | | | |
| <i>F – statistic</i> <i>p–value%</i> | 1.13 34.0 | 0.92 43.6 | 0.51 67.6 | 0.52 66.9 | 0.94 42.7 |
| <i>DEAM encompass**</i> | | | | | |
| <i>F – statistic</i> <i>p–value%</i> | 0.19 90.0 | 0.06 98.1 | 0.04 99.0 | 0.14 93.5 | 1.25 29.7 |

In parentheses: heteroskedasticity and autocorrelation consistent (Newey West) standard error of the coefficients.

* Test of the restrictions : coeff(AEAM)=1; coeff(DEAM)=0; constant=0.

** Test of the restrictions : coeff(AEAM)=0; coeff(DEAM)=1; constant=0.

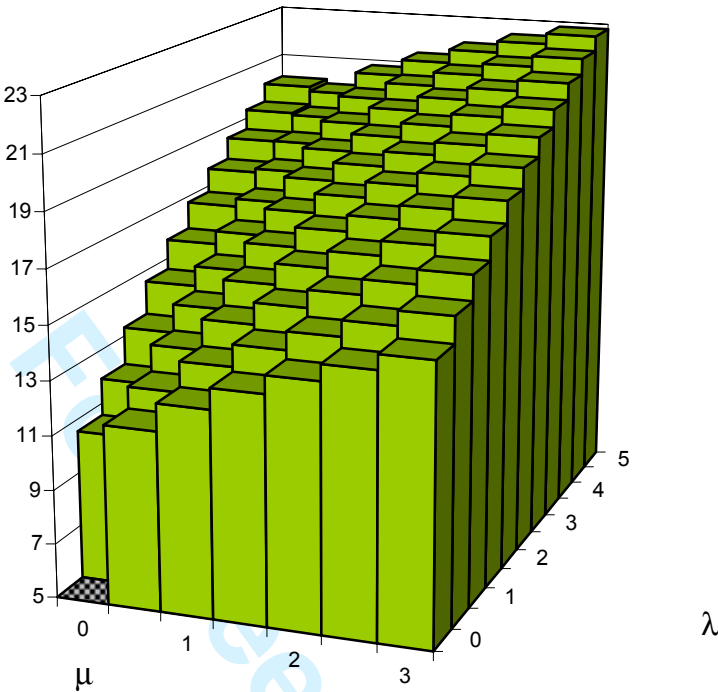
Table 6

Reaction function coefficients and loss values for the optimal, the AEAM-based and the DEAM-based rules

| Parameter values in the loss function: | | Type of rule | Coefficients on: | | | Standard deviation of: | | Loss |
|--|-----------|--------------|----------------------|------------|----------------------|------------------------|------------|-------|
| | | | Annualized Inflation | Output gap | Lagged interest rate | Annualized Inflation | Output gap | |
| $\lambda = 0.1$ | $\mu=0.1$ | FOR | 2.93 | 2.86 | 0.49 | 1.79 | 1.37 | 4.06 |
| | | DEAM-based | 2.46 | 1.75 | 0.69 | 2.18 | 1.68 | 6.41 |
| | | AEAM-based | 1.66 | 1.27 | 0.75 | 2.42 | 1.62 | 6.84 |
| | $\mu=1$ | FOR | 1.18 | 1.23 | 0.67 | 2.18 | 1.29 | 6.41 |
| | | DEAM-based | 0.99 | 0.86 | 0.82 | 2.81 | 1.57 | 11.34 |
| | | AEAM-based | 0.69 | 0.65 | 0.85 | 3.21 | 1.50 | 12.29 |
| $\lambda = 1$ | $\mu=0.1$ | FOR | 2.90 | 3.31 | 0.41 | 1.83 | 1.26 | 5.59 |
| | | DEAM-based | 2.54 | 1.98 | 0.64 | 2.24 | 1.52 | 8.67 |
| | | AEAM-based | 1.64 | 1.42 | 0.70 | 2.63 | 1.42 | 9.50 |
| | $\mu=1$ | FOR | 1.19 | 1.34 | 0.64 | 2.20 | 1.25 | 7.86 |
| | | DEAM-based | 1.02 | 0.92 | 0.81 | 2.84 | 1.50 | 13.46 |
| | | AEAM-based | 0.69 | 0.68 | 0.83 | 3.37 | 1.42 | 14.91 |
| $\lambda = 2$ | $\mu=0.1$ | FOR | 2.88 | 3.68 | 0.35 | 1.89 | 1.20 | 7.10 |
| | | DEAM-based | 2.61 | 2.19 | 0.61 | 2.32 | 1.43 | 10.84 |
| | | AEAM-based | 1.65 | 1.57 | 0.66 | 2.85 | 1.32 | 12.18 |
| | $\mu=1$ | FOR | 1.20 | 1.44 | 0.62 | 2.22 | 1.22 | 9.38 |
| | | DEAM-based | 1.06 | 0.98 | 0.79 | 2.88 | 1.45 | 15.64 |
| | | AEAM-based | 0.70 | 0.72 | 0.82 | 3.54 | 1.35 | 17.70 |

Figure 1

Percentage additional loss, AEAM-based rule vs. DEAM-based rule



Percentage additional loss, AEAM-based rule vs. DEAM-based rule
(as a share of the additional loss with the DEAM-based rule vs. the loss with the FO rule)

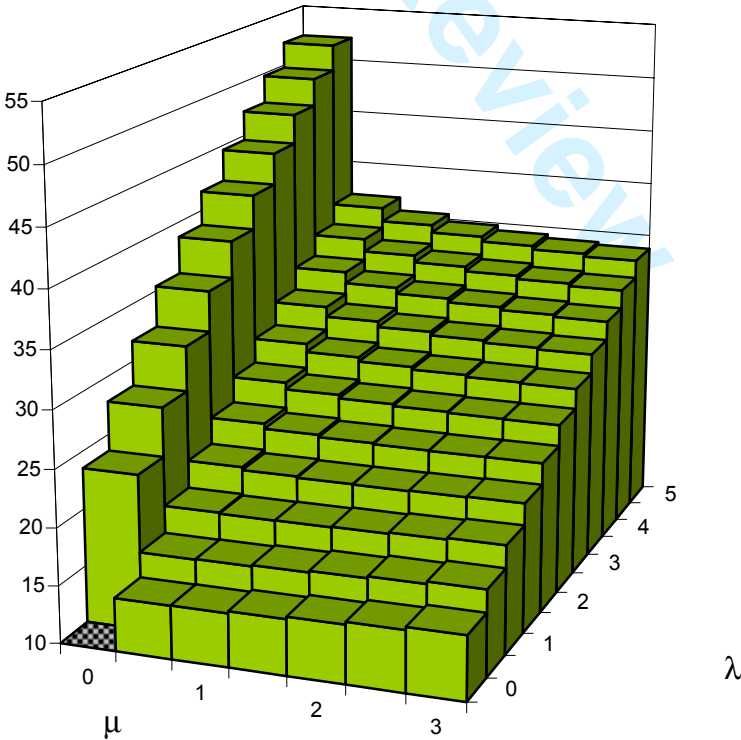


Figure 2

Inflation - output gap optimal frontiers

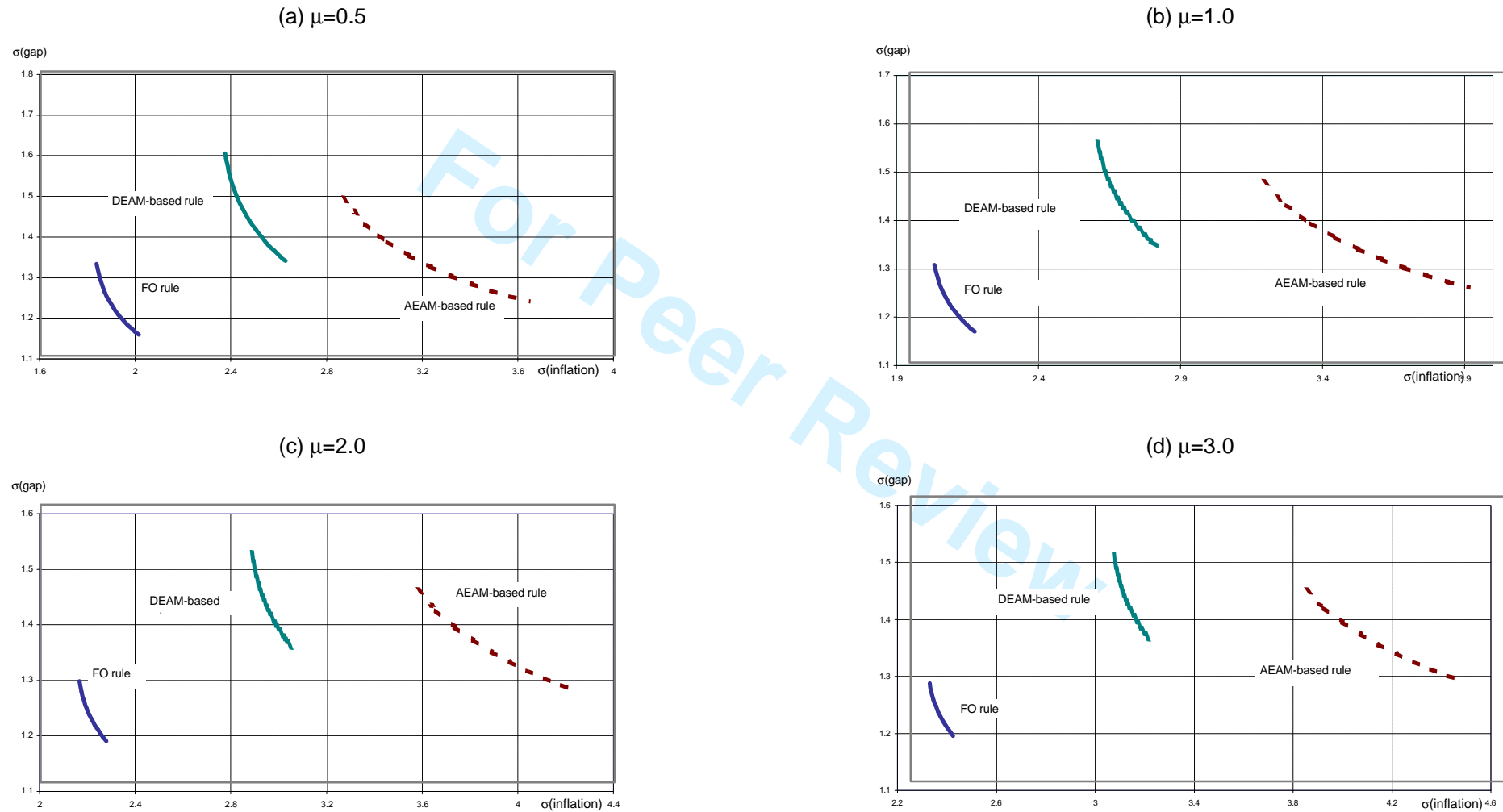
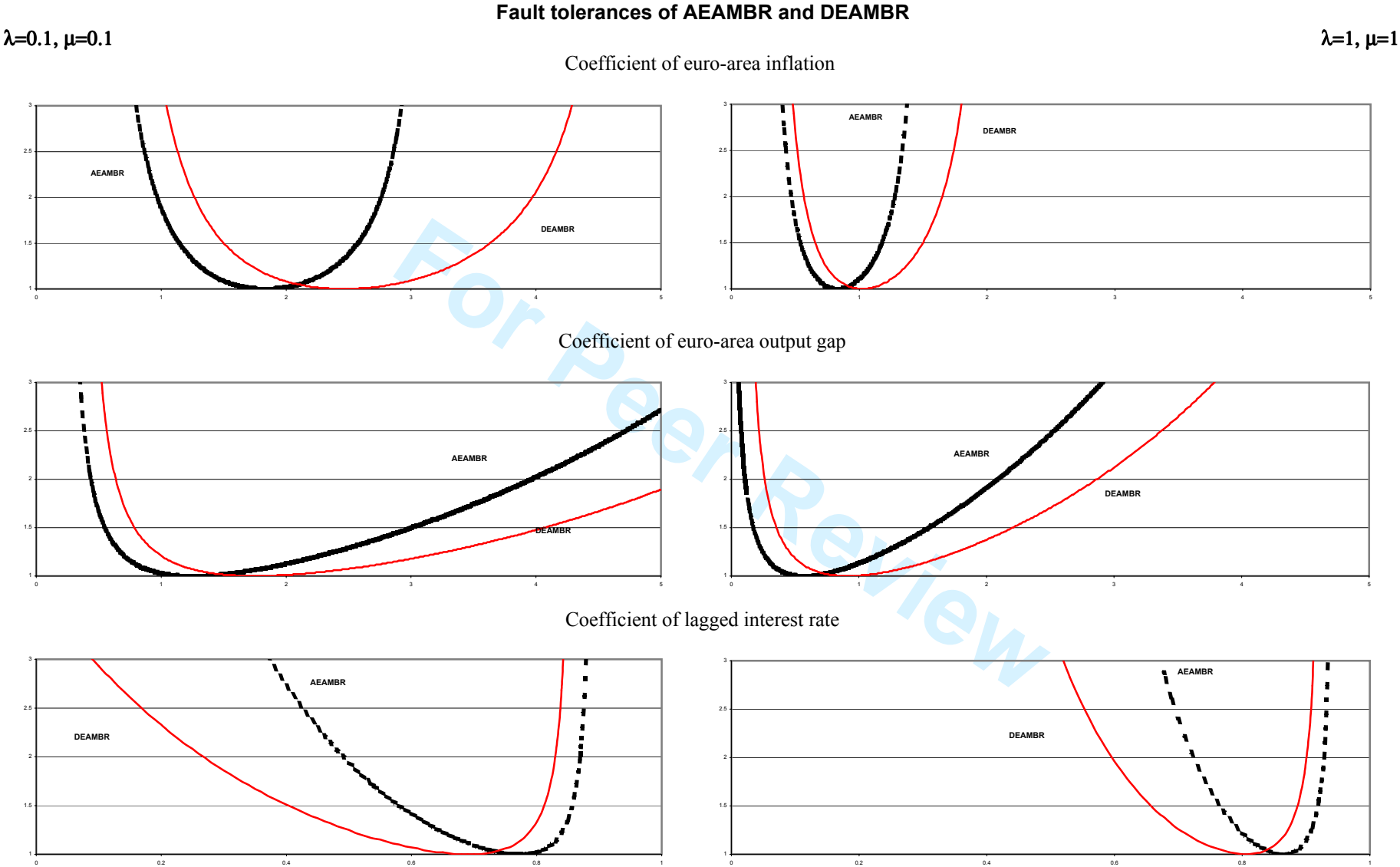


Figure 3

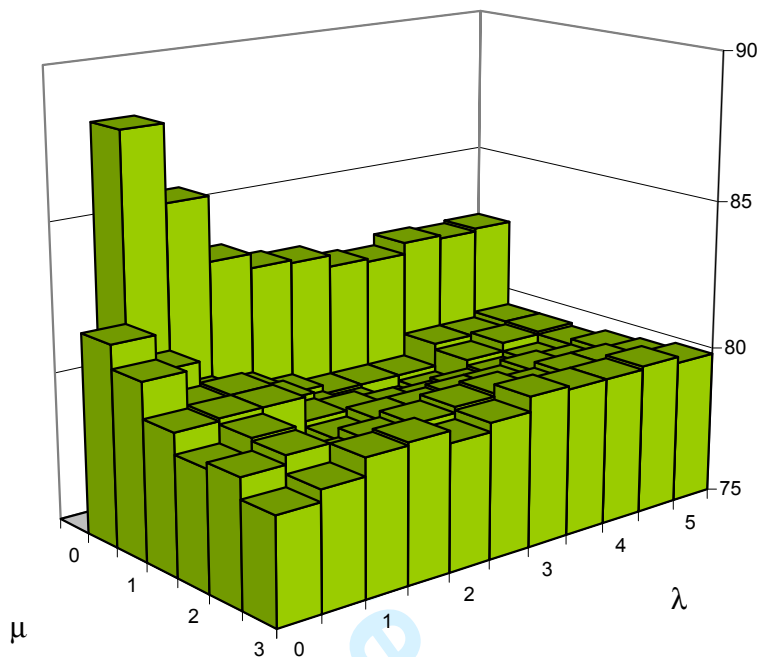


Note: The curves in the chart show, for each rule, the ratio between the loss that obtains with the corresponding parameter value on the x-axis and the loss delivered by the first-best optimal policy.

Figure 4

Random drawings from distribution of estimation residuals, DEAM-based rule vs. AEAM-based rule

Percentage of cases in which the DEAM-based rule outperforms the AEAM-based rule



Random drawings from distribution of estimated DEAM residuals Testing the significance of the underperformance of the AEAM-based rule

Test that the average loss associated with the DEAM-based rule
is lower than the one associated with the AEAM-based rule
(reverse scale)

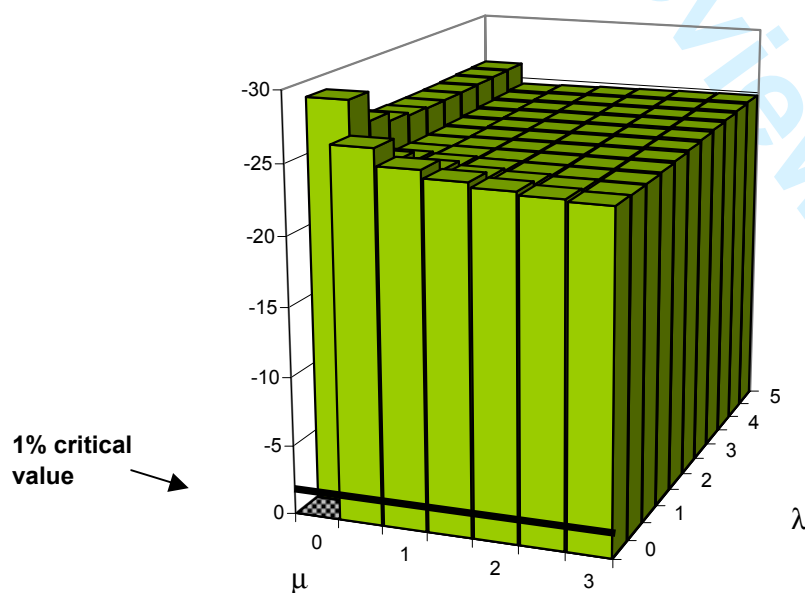
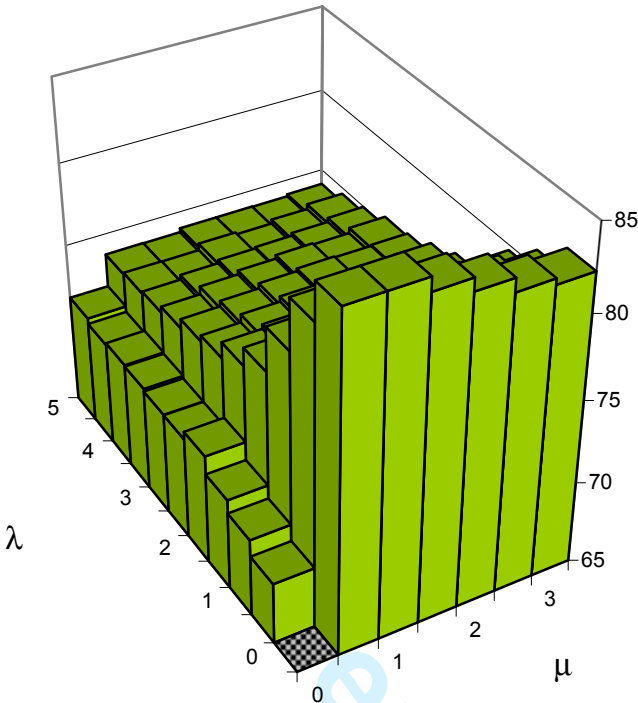


Figure 5

Random drawings from distribution of estimated DEAM parameters,
DEAM-based rule vs. AEAM-based rule

Percentage of cases in which the DEAM-based rule outperforms the AEAM-based rule



Random drawings from distribution of estimated DEAM parameters
Testing the significance of the underperformance of the AEAM-based rule

Test that the average loss associated with the DEAM-based rule
is lower than the one associated with the AEAM-based rule
(tail probability)

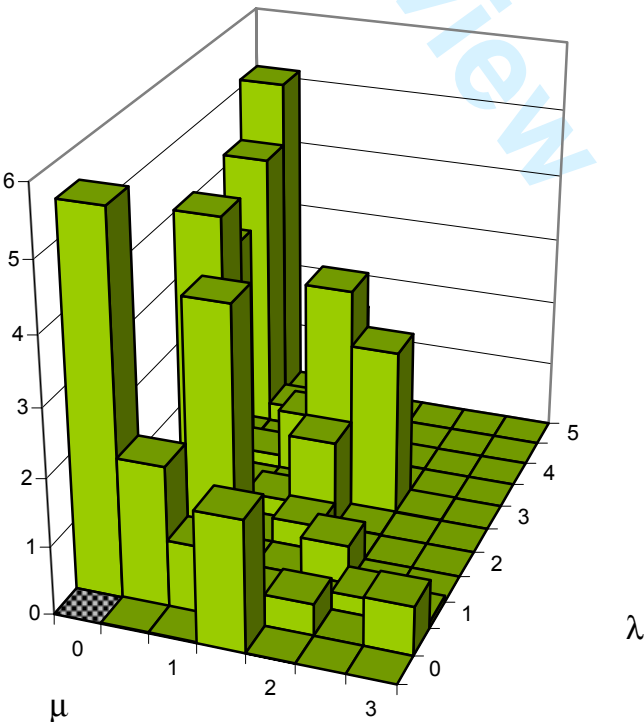
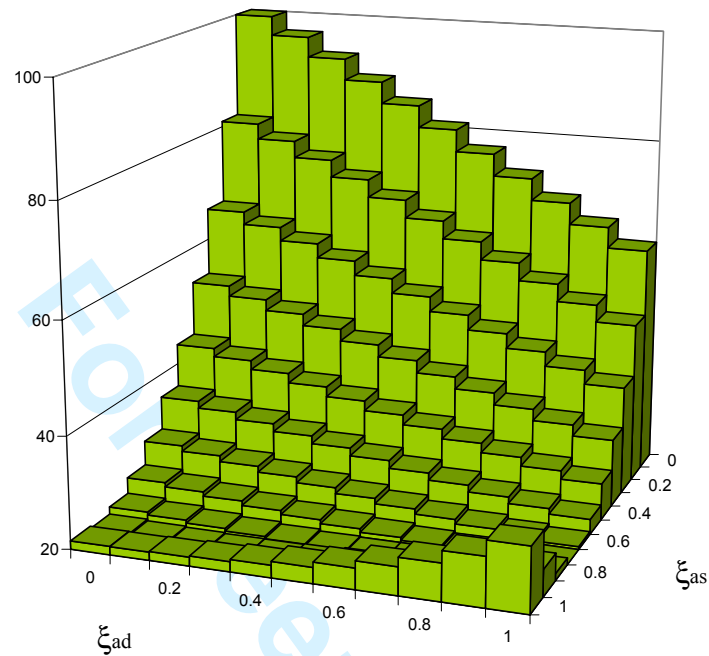


Figure 6

Additional welfare loss, AEAM-based rule vs. DEAM-based rule
 (with gradual convergence of Phillips curve and aggregate demand stochastic processes, $\lambda = \mu = 1$;
 the additional loss in the case of no convergence is set=100)



The economic consequences of euro area modelling shortcuts

Libero Monteforte, Stefano Siviero*

Abstract

Should euro-area economies be modelled in an aggregate (area-wide) fashion or in a disaggregate (multi-country) one? This paper tackles that question from both a statistical and an economic viewpoint. From a statistical viewpoint, aggregation bias criteria are found to signal that the degree of structural heterogeneity among euro-area economies is such that the loss of information entailed by an aggregate modelling approach may be far from trifling. From an economic viewpoint, we investigate the following issue: Are those statistically detectable heterogeneities of any practical relevance when it comes to supporting monetary policy decision-making? To provide an answer to this question, we compute simple optimal monetary policy reaction functions on the basis of either an aggregate model or a disaggregate one, and compare the associated welfare losses. The results suggest that the welfare under-performance of an area-wide-model-based rule is not only non negligible, but also robust with respect to a number of sensitivity analyses.

1 Introduction

The introduction of the single currency in a number of European countries on January 1st, 1999, raised a number of novel challenges for European policy-makers, economic scholars and practitioners alike. Concerning specifically macro-economic modelling challenges, monetary policymaking for the euro area as a whole requires that policy analyses and projections, previously run on a country-by-country basis, be extended to cover all economies in the area in a consistent way. This poses the following basic issue: Should the Eurozone economy be modelled as if it was one single, large economy (area-wide, or aggregate, approach)? Or, alternatively, should disaggregate country data be used to build inter-linked single-country models (multi-country, or disaggregate, approach)?

In principle, aggregate models are sub-optimal whenever the individual units being aggregated display some degree of heterogeneity. Most empirical studies of the euro-area economy indicate that the extent of the divergences in the

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behaviour of the participating economies —particularly as far as the monetary transmission mechanisms is concerned— is far from being negligible: relevant peculiarities still exist, and they are likely to reflect deep structural differences.¹

Despite the wealth of evidence on the heterogeneity of euro-area economies, few systematic efforts have been made so far to assess the statistical significance of that heterogeneity and to test whether the modelling of aggregate euro-area data —as opposed to individual country ones— is a sound econometric strategy. Furthermore, to our knowledge no attempt has been made to explore the economic implications of that issue.

This paper tackles the aggregate/disaggregate euro-area modelling trade-off from both a statistical and, most relevantly, an economic viewpoint.

From a statistical viewpoint, the greater parsimony and transparency of aggregate models usually comes at the cost of an aggregation bias. We briefly report on the results of checking —using a number of criteria and diagnostics proposed in the literature— whether signs of aggregation bias may be detected in the estimates of a stylised model of the euro area, and assess the size of that bias. We find that the empirical evidence consistently supports the conclusion that ignoring the heterogeneity of euro-area countries entails statistically significant misuse of information.

The core of the paper is the analysis of the aggregate/disaggregate trade-off from an economic viewpoint: We propose a model-selection-criterion that relies on economic arguments rather than statistical ones. We begin by remarking that statistical evidence of aggregation bias cannot *per se* be taken to imply that the use of aggregate econometric tools would result in dramatically unreliable analyses and insight, and hence in markedly sub-optimal economic decisions. To explore whether or not that would be the case, we assess the performance of two hypothetical euro-area monetary policy-makers: The first relies on an aggregate model of the euro area, while the second takes her decisions on the basis of a disaggregate model. We then explore whether the performance of the former policy-maker would be perceivably worse than that of the latter. Our approach may thus be viewed as proposing a policy-based metric for appraising the economic relevance of structural heterogeneities across euro-area economies.² Should this analysis suggest that no big welfare losses are at stake, an area-wide modelling approach might remain the preferred option, regardless of what the standard statistical checks of aggregation bias may indicate. Our findings suggest that the additional welfare losses that would be incurred by relying on an aggregate modelling approach —as opposed to a disaggregate one— may be far from trifling. This conclusion, while necessarily model-dependent, appears to be robust with respect to a number of sensitivity analyses.

¹A (very) partial list of works that have a bearing on this issue includes Ramaswamy and Sloek (1997), Dornbusch, Favero and Giavazzi (1998), Guiso, Kashyap, Panetta and Terlizzese (1999), Clements, Kontolemis and Levy (2001), Ciccarelli and Rebucci (2002), Perman and Tavera (2005), Dedola and Lippi (2005), and the papers collected in Angeloni, Kashyap and Mojon (2003). Not much effort has yet been devoted to trying to identify, with the aid of macroeconomic models, the structural determinants underlying the observed heterogeneities. Fragmentary evidence may be found in van Els, Locarno, Mojon and Morgan (2003).

²From the viewpoint of the debate on robust rules (see the contributions in Taylor (1999), as well as Levin and Williams (2003) and Adalid, Coenen, McAdam and Siviero (2005)), this paper may be viewed as focussing on one particular type of robustness (i.e., robustness with respect to the assumption of aggregability).

A few papers have addressed the aggregate/disaggregate trade-off in the context of euro-area monetary policymaking from different angles: De Grauwe and Piskorski (2001) and Aksoy, De Grauwe and Dewachter (2002) investigate the implications of nationalistic attitude of the ECB Governing Council members, and assess how the performance of euro-area monetary policy is affected by different definitions of preferences (specifically, they contrast loss functions defined over area-wide aggregates and loss functions that are weighted averages of the individual national central banks' ones). Angelini, Del Giovane, Siviero and Terlizzese (2007) focus on the role that should, or should not, be played by information at the national level in setting the single monetary policy of the euro area, under the maintained assumption that preferences are defined over area-wide aggregates. They find that, by reacting to national information, the euro-area central bank attains significant reductions in (aggregate) inflation and output variability, as opposed to the case in which the interest rate reacts to area-wide variables only. This paper may thus be viewed as filling a gap in the literature, by focussing on the implications of the aggregate/disaggregate trade-off on modelling-for-policy choices. Contrary to De Grauwe and Piskorski (2001) and Aksoy, De Grauwe and Dewachter (2002), we maintain the assumption that the policy-maker's preferences be area-wide; contrary to Angelini, Del Giovane, Siviero and Terlizzese (2007) we do not assume modelling choices to be given. Rather, we are interested in testing whether adopting an aggregate or a disaggregate modelling strategy may significantly alter the performance of the euro-area monetary policy-maker.

In short, our findings are as follows: Disaggregate euro-area modelling appears to be sharply preferable from a welfare viewpoint; aggregate modelling results in the monetary policy-maker being arguably too timid when it comes to reining in average inflation across a number of heterogeneous economies.

The paper is organized as follows. Section 2 shortly describes the two basic modelling options faced by euro-area modellers and presents and compares the main features of the stylised aggregate and disaggregate models used in the remainder of the paper. Section 3 briefly presents the results of a number of aggregation bias tests and criteria. Section 4 presents our approach to appraising the economic relevance of structural heterogeneity across euro-area countries. Section 5 offers a quantification of the additional welfare losses that would be incurred if euro-area monetary policy was to rely on an aggregate model rather than a disaggregate one, and investigates the model (and rule) features from which those additional losses originate. Section 6 provides an estimate of the significance of the additional losses. Section 7 explores the robustness of the main results, addressing issues such as: How would the results change should euro-area economies tend to converge in the future? Would the conclusions be different if the competing rules were assumed to be forward-looking? Section 8 concludes.

2 Two simple models of the euro area

When it comes to building empirical tools for euro-area forecasting and policy analysis purposes, two basic options are available: as a first alternative, one could build a disaggregate, or multi-country, model, i.e., a model describing the functioning of the economic mechanisms in the individual countries of the area

and the inter-linkages amongst them; in such a model, country-specific features may be reflected by either the structure of the country sub-models and/or the value of their parameters. As a second, much less onerous, alternative, one may first aggregate the individual country data³ and model the latter as if they referred to one single, large and homogeneous economy (aggregate, or area-wide, model).⁴

In this paragraph we describe the two (aggregate and disaggregate) simple AS-AD models used in the remainder of the paper and present their main properties. Several variants of models of the same kind as the ones we consider have been widely used in the literature on optimal policy rules.⁵ The models we use here have also been employed in two papers assessing the role of different information and different models in the conduct of euro-area monetary policy. In Angelini, Del Giovane, Siviero and Terlizzese (2007) the use of a monetary policy reaction function specified on country-specific variables is compared with a rule specified on area-wide variables, using the same disaggregate model as in this paper. In Adalid, Coenen, McAdam and Siviero (2005) the same model takes part in a four-model quest for a robust euro-area monetary policy rule. Finally, Monteforte (2007) runs extensive econometric testing of aggregation bias using the same models as in this paper.

Both models presented below are purely backward-looking and are thus potentially affected by the issue of policy-dependent parameters (Lucas Critique).⁶ However, the empirical evidence presented below overwhelmingly supports the hypothesis of structural stability, even for the most recent period, when, arguably, a major shock (the launching of the single monetary policy itself, no less) occurred in the policy regime. Also, models belonging to the same broad family as the ones used here are largely (though not exclusively) relied upon by the euro-area monetary policy-maker.

The Aggregate Euro Area Model (AEAM) is a simple two-equation model estimated using aggregate data for the three largest economies in the euro area (Germany, France and Italy, jointly accounting for over 70 per cent of the area GDP). It includes an aggregate supply equation (also referred to as Phillips curve) and an aggregate demand equation (also referred to as IS curve). The first equation determines inflation as a function of lagged inflation and the output gap; the sum of the coefficients on lagged inflation is constrained to unit so that the Phillips curve is of the accelerationist type.⁷ The second equation relates the output gap to its own lagged values and the real interest rate.⁸

³Labhard, Weeken and Westaway (2001) argue that the actual choice of the aggregating function is unlikely to affect the properties of the model in any significant way. The aggregating functions used in this paper are briefly described below.

⁴Both approaches are being pursued in practice, even by the same institutions. For instance, the European Central Bank (ECB) maintains an aggregate econometric model (see Fagan, Henry and Mestre (2001)), called AWM (Area Wide Model), and a disaggregate one, called MCM (Multi Country Model). Also, the euro-area projections by the Eurosystem (the institution comprising the ECB and the national central banks of euro-area countries) are the result of a multi-staged process that involves both country-specific and area-wide models (see ECB (2001)).

⁵See Rudebusch and Svensson (1999) for a strictly backward-looking version and Clarida, Gali and Gertler (1999) for a fully forward-looking one.

⁶Lucas (1976). See, however, Sims (1982), Farmer (1991), Favero and Hendry (1992) and Altissimo, Siviero and Terlizzese (2002) for a number of arguments that mitigate the implications of the Lucas Critique.

⁷A Wald test cannot reject the restriction (p-value of 18.8 per cent).

⁸Neither equation includes foreign variables; in other words, the euro area is modelled as a

A general-to-specific modelling approach was followed in searching for a satisfactory empirical specification, starting with 6 lags for all variables on the right-hand-side of the two equations. The final specification is the following:

$$\begin{aligned}\pi_{t+1} &= \alpha_1\pi_t + (1 - \alpha_1)\pi_{t-3} + \eta_0 y_{t+1} + u_{t+1} \\ y_{t+1} &= \theta_1 y_t + \psi_2(i_{t-1} - 4 \cdot \pi_{t-1}) + v_{t+1}\end{aligned}\tag{1}$$

where π_{t+1} is the quarter-on-quarter consumer inflation rate; y_{t+1} is the output gap; i_{t+1} is the short-term interest rate; $i_{t+1-k} - 4 \cdot \pi_{t+1-k} = r_{t+1}$ is a measure of the ex-post real interest rate.⁹

The model was estimated with GMM, using White's diagonal weighting matrix, thus allowing for the possibility of correlation between the residuals of the two equations. As to the interest rate, we assume it to affect the output gap only with a lag, consistently with most empirical evidence; estimation could hence be carried out without augmenting the estimated model with an interest rate reaction function. The sample period extends from 1978.Q1 to 2004.Q4, totalling 108 quarterly observations. The estimation results are presented in Table 1.

The Disaggregate Euro Area Model (DEAM) includes, for each of the three largest euro-area countries, the same set of equations as the AEAM. The specification of both the aggregate supply and aggregate demand equations is similar to the one adopted in the AEAM but, in addition, it allows for cross-country linkages. Specifically, in the AS equation inflation in any given country depends not only on its own lagged values and the output gap, but also, at least in principle, on inflation "imported" from the other two countries (inflation imported from either country is given, in estimation, by the sum of inflation in that country and the rate of change of the relevant bilateral exchange rate; the latter term is obviously dropped in the simulations below, consistently with the adoption of the single currency as of January 1st, 1999). Analogously to the case of the AEAM, the sum of the coefficients on lagged and imported inflation is constrained to be 1.¹⁰ Similarly, in the AD equation the output gap in any of the three countries depends on its own lagged values and on the corresponding real interest rate, as in the AEAM; in addition, it may react to the output gap in the other two countries, reflecting trade linkages.

As the model set-up allows for instantaneous cross-country linkages, it was estimated with 3SLS. The sample period extends from 1978.Q1 to 2004.Q4, as for the AEAM.¹¹

closed economy, similarly to what is systematically done for the US, and increasingly for the euro area as well.

⁹The source of data is the ESA-95 National Accounts for inflation and the output gap, and the BIS data-bank for the short-term interest rate. Inflation is measured by the quarter-on-quarter rate of change of the (seasonally adjusted) households' consumption deflator. Potential output was estimated by applying a band-pass filter (Baxter and King (1995)) to the (log) GDP, selecting frequency components of 32 quarters and higher, with a truncation of 16 quarters. National variables were aggregated using a fixed-weight procedure. For inflation, 1999 PPP consumer spending shares were used. For the output gap, the weights are given by 1999 PPP real GDP shares. For interest rates, the weights are the PPP nominal GDP shares computed by the OECD. The GDP and consumer spending weights are, respectively 0.43 and 0.44 for Germany, 0.29 and 0.27 for France, 0.28 and 0.29 for Italy.

¹⁰A Wald test on the restriction cannot reject with P values of 16,8%, 5,2% and 83,3% for Germany, France and Italy, respectively.

¹¹For most of the sample period, the exchange rates among Germany, France and Italy,

The general form of the two-equation sub-model for country j is the following:¹²

$$\begin{aligned}\pi_{t+1}^j &= \sum_{k=1}^p \alpha_{j,k} \pi_{t+1-k}^j + \sum_{i \neq j} \sum_{k=0}^p \beta_{j,i,k} (\pi_{t+1-k}^i + \dot{c}_{t+1-k}^{i,j}) + \sum_{k=0}^p \eta_{j,k} y_{t+1-k}^j + u_{t+1}^j (2) \\ y_{t+1}^j &= \sum_{k=1}^p \theta_{j,k} y_{t+1-k}^j + \sum_{i \neq j} \sum_{k=0}^p \varphi_{j,i,k} y_{t+1-k}^i + \sum_{k=1}^p \psi_{j,k} (i_{t+1-k}^j - 4 \cdot \pi_{t+1-k}^j) + v_{t+1}^j\end{aligned}$$

where: $j = G, F, I$ denotes the different countries and $\dot{c}_{t+1-k}^{i,j}$ is the quarter-on-quarter rate of change of the exchange rate between country i and country j (units of country j 's currency for 1 unit of country i 's currency).

The starting specification included on the right-hand-side of each estimated equation the first 6 lags of all relevant variables. Joint estimation of the three sub-models resulted, after dropping all insignificant lags, in a much more parsimonious specification (see Table 2).

The AEAM and DEAM were estimated with data straddling the introduction of the euro. It may thus be feared that, notwithstanding their performance in the estimation period, those models might be affected by structural discontinuities following the birth of the euro area. To explore whether this is the case, we performed stability analysis for both models; the test is particularly challenging, as we checked whether the model estimates based solely on pre-euro data (1978.Q1 to 1998.Q4) remain statistically stable over a sample period consisting exclusively of post-euro observations (1999.Q1 to 2004.Q4).

The results of direct stability testing are shown in Tables 3 and 4 and Figures 1 and 2. For both models, the empirical evidence systematically rejects the hypothesis of parameter instability. Furthermore, Figure 2 shows no detectable signs of convergence of the DEAM parameters (actually, the cross-country dispersion of the parameters tends to be larger at the end of the sample than it was before the introduction of the euro).

The impulse responses of the models —computed after augmenting both models with the same Taylor-type stabilizing policy rule— are broadly in line with well-established stylized facts about the euro-area economy. In particular: (i) any shock tends to result in remarkably persistent deviations from the equilibrium; (ii) a monetary policy shock initially affects output more than inflation; (iii) the full response of output and inflation to an interest rate shock takes some time to materialize.¹³ The general pattern of most impulse responses is similar in the two models. However, deviations from the equilibrium tend to be more pronounced and persistent in the DEAM; also, because of the generally more

though constrained by the ERM of the EMS, were not fixed; lagged values of all variables included in the model were used as instruments for the exchange rates. As in the AEAM, the interest rate enters the AD equations with a lag.

¹²In keeping with the approach followed in similar literature, neither the AEAM nor the DEAM that we use for our experiments below include any constant terms, i.e., they may be taken to provide a description of the functioning of the euro area economy in the neighborhood of equilibrium. This amounts to implicitly assuming that the same equilibrium values apply to all countries, a condition that does not necessarily hold in the sample period, particularly regarding the (implied) equilibrium real interest rates.

¹³For more details, see the mimeo version of this paper (Monteforte and Siviero (2003)). As a term of comparison, see the evidence presented in the papers collected in Angeloni, Kashyap and Mojon (2003).

pronounced impact of aggregate supply and aggregate demand shocks in the DEAM, monetary policy tends to be more activist than in the AEAM, even if both models are augmented with exactly the same Taylor-type rule.

Finally, while the representation of the functioning of the (three largest economies in the) euro area provided by either the AEAM or the DEAM is admittedly rather crude, a comparison of the differences between (larger-size) aggregate and disaggregate econometric models basically leads to the same conclusions as above.¹⁴

3 Direct aggregation bias investigation

Analysis of aggregation bias dates back to Theil's (1954) seminal work. In that set-up, the aggregation bias vanishes, under the assumption that both the aggregate and disaggregate equations are correctly specified, in only two cases: (i) micro homogeneity (i.e., when the parameters of any disaggregate equation are identical to those of any other); (ii) compositional stability (i.e., when the ratio between each disaggregate exogenous variable and the corresponding aggregate one is constant over time). If none of those two conditions hold, the aggregate relationship has an additional error component as compared with the disaggregate ones; such additional components is what Theil (1954) labelled "aggregation bias".

The most natural criterion to assess the relevance of the aggregation bias consists of comparing the sum of squared residuals associated with the disaggregate equations with that of the aggregate one, as first proposed by Grunfeld and Griliches (1960). Pesaran, Pierse and Kumar (1989) proposed a slightly different criterion, which corrects for small sample bias in the sum of square residuals. If the micro equations are correctly specified, the latter is necessarily smaller than or at most equal to the former by construction. However, the opposite may well happen in practice if the equations that are compared are affected by misspecification errors. Monteforte (2007) developed a factor-analysis-based approach for aggregation bias testing. In short, that approach rests on identifying the idiosyncratic components of the micro equations: intuitively, the larger those components, the less appropriate the assumption of aggregability. Zellner and Tobias (2000) and Baltagi, Griffin and Xiong (2000) advocated assessing the relevance of the aggregation bias on the basis of the relative forecast performance of the aggregate and disaggregate models.

In the case at hand, all those criteria and tests consistently point in the direction of rejecting the hypothesis of no aggregation bias.

Grunfeld and Griliches's (1960) and Pesaran, Pierse and Kumar's (1989) criteria for the AEAM and DEAM are shown in Table 5. Clear signs of aggregation bias emerge on the basis of both criteria, particularly in the case of the aggregate supply (Phillips Curve) equations. The DEAM model outperforms the AEAM also in term of forecasting ability, as shown by the RMSE errors at various step in Table 6. Analogous indications are provided by the criteria based on factor models.¹⁵

Our results are consistent with those of Mayes and Virén (2000), who find that asymmetries across euro-area aggregate supply curves are very pronounced;

¹⁴A thorough comparison may be found in Monteforte and Siviero (2003).

¹⁵More detailed results may be found in Monteforte (2007).

Fabiani and Morgan (2003) also find evidence of asymmetry of Phillips curves. These results are consistent with those of Perman and Tavera (2005), finding increasing dispersion in the unemployment-output relation across euro area countries.

To sum up, all available evidence indicates that the hypothesis of no aggregation bias cannot be accepted, especially in the case of the aggregate supply equations.

4 Indirect aggregation bias investigation: Design of experiment

In the light of the results of the previous section, a disaggregate modelling approach of the euro area appears to be statistically sounder than its alternative. It remains to be ascertained whether it is also preferable from an economic viewpoint. To do this, we compare the performance of two hypothetical European monetary policy-makers. The first policy-maker is posited to assume that the functioning of the euro area economy is well represented by the AEAM; by contrast, the second policy-maker's reaction is computed on the basis of the DEAM.

Since the vector of state variables is different for the two models, the corresponding optimal instrument rules (i.e., rules that exploit all the information provided by the whole set of state variables; since such rules attain the best possible outcome, we call them “fully optimal” and label them “FO”) would not be easily comparable. We thus impose that both rules belong to the Taylor-type family (i.e., the arguments of both rules are the current area-wide inflation and output gap and the lagged value of the policy instrument only).¹⁶ For the sake of making the comparison as fair as possible, we further require the DEAM-based rule (henceforth, DEAMBR) to respond to area-wide aggregates only, as is necessarily the case for the AEAM-based rule (AEAMBR).

A standard time-separable quadratic loss function is assumed, its arguments being the euro area average inflation rate and output gap, and a term that attaches a cost to the volatility of the policy instrument; i.e.:

$$L_t = E_t \sum_{\tau=0}^{\infty} \delta^{\tau} [(4\pi_{t+\tau})^2 + \lambda \cdot y_{t+\tau}^2 + \mu \cdot (\Delta i_{t+\tau})^2] \quad (3)$$

where δ is a discount factor, and λ and μ are parameters that reflect the policy-maker's preferences; $4\pi_t$ is the annualised quarter-on-quarter consumer inflation rate. Note that eq. (3) implies that the euro-area policy-maker is only interested in euro-area average outcomes, in line with the official Eurosystem's view of the monetary policy objective and strategy.

For $\delta \rightarrow 1$ the sum in eq. (3) may be interpreted as the unconditional mean of the period loss function (see, e.g., Rudebusch and Svensson (1999)), which is given by the weighted sum of the unconditional variances of the target variables:

$$L_t = \text{var}[4\pi_t] + \lambda \cdot \text{var}[y_t] + \mu \cdot \text{var}[\Delta i_t] \quad (4)$$

¹⁶The simple optimal monetary policy rules we consider have been used in earlier works modelling the monetary policy of the ECB (see, e.g., Garcia-Iglesias (2007)).

In the following we adopt the loss function defined as in eq. (4). The search for simple optimal policies was repeated for a range of values for both λ and μ , spanning from the case in which the monetary policy-maker is only interested in inflation ($\lambda = \mu = 0$) to the opposite extreme, in which the policy-maker attaches a comparatively high cost to deviations of the output gap from its equilibrium value and to the volatility of the policy-controlled interest rate ($\lambda = 2, \mu = 1$).

The two competing rules may thus be synthetically described as follows:

AEAMBR

$$\min_{\gamma_1^A, \gamma_2^A, \gamma_3^A} E_t \sum_{\tau=0}^{\infty} L_{t+\tau} = \min_{\gamma_1^A, \gamma_2^A, \gamma_3^A} E_t \sum_{\tau=0}^{\infty} [(4\pi_{t+\tau})^2 + \lambda \cdot y_{t+\tau}^2 + \mu \cdot (\Delta i_{t+\tau})^2]$$

s.to:

- AEAM (see Section 2)
- $i_t = \gamma_1^A \cdot (4\pi_t) + \gamma_2^A \cdot y_t + \gamma_3^A \cdot i_{t-1}$

and:

DEAMBR

$$\min_{\gamma_1^M, \gamma_2^M, \gamma_3^M} E_t \sum_{\tau=0}^{\infty} L_{t+\tau} = \min_{\gamma_1^M, \gamma_2^M, \gamma_3^M} E_t \sum_{\tau=0}^{\infty} [(4\pi_{t+\tau})^2 + \lambda \cdot y_{t+\tau}^2 + \mu \cdot (\Delta i_{t+\tau})^2]$$

s.to:

- DEAM (see Section 2)
- $i_t = \gamma_1^M \cdot (4\pi_t) + \gamma_2^M \cdot y_t + \gamma_3^M \cdot i_{t-1}$

Let us now tackle the crucial issue of how the performance of these two rules is to be compared. The statistical evidence presented in Section 3 clearly indicates that the DEAM provides a more reliable description of the functioning of the euro-area economy than the AEAM. Accordingly, we assess, using the DEAM and the corresponding variance-covariance matrix of residuals, the welfare function values associated with the optimised AEAMBR and DEAMBR, computed as described above.

Given the way in which the two rules are compared, it is obviously the case that the AEAMBR cannot outperform the DEAMBR by construction. However, the under-performance of the AEAMBR might well be trifling. Our results below suggest that the welfare distance between the two rules is significantly and robustly non-negligible.

As a benchmark, we also compute, on the basis of the DEAM, the FO rule and the associated optimised target variances and welfare loss.¹⁷ This third set of results is used to compare the gains attainable with the DEAMBR with the (larger) ones that could be achieved by relying on the rule that, by definition, performs best within the DEAM.

¹⁷For this purpose, we solve a standard stochastic linear regulator problem (see Chow (1970), Sargent (1987), and, for an application to the issue of optimal monetary policy design, Rudebusch and Svensson (1999)).

5 Main results

The main results of our experiments are shown in Figures 3 and 4 and Table 7.¹⁸ Let us focus first on the outcomes of the two competing rules (Figure 3). The top chart of the figure reports the percentage increase in the optimised value of the objective function if the AEAMBR is followed instead of the DEAMBR. The welfare losses are far from negligible, being smallest (between 10 and 20 per cent) in the neighborhood of $\lambda = \mu = 0$, excluding, however, the latter case: in case the policy-maker only cares about inflation, the welfare loss entailed by the AEAMBR is over 32 per cent. The loss exceeds 20 per cent for most of the preference parameter combinations, particularly if the weights of either the output gap or the volatility of the policy instrument are relatively high. The key message is that ignoring the structural differences among the euro area economies, and so adopting a model that treats them as a single and homogeneous “whole,” tends to lead to a sizeable worsening of the performance of monetary policy, particularly if the policy-maker only cares about inflation.¹⁹

The bottom chart of Figure 3 reports the same results in relative terms, using the FO rule as a benchmark; the chart suggests that an hypothetical policy-maker relying on the AEAMBR would go a long way towards further worsening the distance (measured in terms of welfare) between the DEAMBR and the FO rule. In particular, the AEAMBR implies an additional loss ranging from about 40 per cent to over 110 per cent of the loss that is incurred if the DEAMBR, rather than the FO rule, is followed. Thus, adopting the best possible rule as a benchmark, the gains attainable by using the DEAMBR rather than the AEAMBR are considerable.

The results can be assessed directly in terms of the optimised unconditional standard deviations of inflation, the output gap and interest rate changes. This is done in Figure 4, which shows the optimal inflation/output gap frontiers (in terms of optimized standard deviations of those variables) for the AEAMBR, DEAMBR and FO rule. For each competing rule the frontier has been computed, for given μ , by letting λ take a grid of values between 0 (north-west) and 2 (south-east).

Can one trace these outcomes back to the properties of the different optimal rules, and in particular to the optimised parameters on inflation, the output gap and the lagged interest rate in the monetary policy reaction functions? A selection of the latter are presented in Table 7. Compared with the DEAMBR, the AEAMBR is systematically “not reactive enough” to either inflation or the output gap; for instance, for $\lambda = \mu = 1$, the optimal response to inflation is 0.94 according to the DEAMBR, but only 0.67 in the AEAMBR. Similarly for the output gap, and for all combinations of loss function weights. The AEAMBR would thus result in the policy-maker’s reaction to the state of the economy being arguably too timid.

Further insight on the nature of the two rules is provided by “Fault tolerance analysis,” as proposed by Levin and Williams (2003). Figure 5 shows the

¹⁸Most of the computations relied on Matlab routines (in turn calling AIM to compute the state-space representation of the models; AIM is available on the website of the Board of the Federal Reserve System). The simulations with random drawings from the distribution of estimated residuals were run in Speakeasy/Modeeasy+. All software codes are available from the authors upon request.

¹⁹The countries that would benefit the most from adopting the DEAMBR rather than the AEAMBR are Germany and France.

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increase in the welfare loss that arises as the parameters of the policy rules move away from the optimal ones. The results suggest that the degrees of fault tolerance of the two rules are not markedly dissimilar, although the DEAMBR tends to be somewhat more tolerant for the inflation and output gap coefficients. The results are heavily affected by the loss function weights: specifically, the degree of fault tolerance declines sharply, for all rules and for all parameters, as the weights of the output gap and the interest rate volatility increase.

6 Testing the significance of the results

This Section investigates whether the results above are significant. To do so, we perform two stochastic simulation exercises.

The first exercise consists of extracting 1,000 replications from the set of estimated residuals and simulating the DEAM, for each replication, under either one or the other of the two competing rules.²⁰ The results show that the DEAMBR delivers a better outcome than the alternative in the overwhelming majority of replications (always at least 80 per cent, and virtually 100 per cent for $\lambda = \mu = 0$); see the top chart of Figure 6). Hence, not only is the gain large on average, but is also systematic. We also formally tested the hypothesis that the average welfare loss associated with following the DEAMBR is lower than the average loss with the AEAMBR.²¹ The results are overwhelmingly supportive of the hypothesis: for all combinations of policy parameters the tail probability of the test is virtually zero (the values of the test for all λ 's and μ 's are shown in the bottom chart of Figure 6).

The second exercise explicitly accounts for the stochastic nature of the estimated model coefficients. In the previous section, the DEAM was assumed to accurately describe the functioning of the economy; the stochastic nature of the estimated parameters was thus ignored. We mean to investigate whether our main results are robust with respect to relaxing that assumption. To account for the variability of the estimated coefficients we extract 2,000 replications from the empirical distribution of the estimated DEAM coefficients and, without re-computing the DEAMBR and AEAMBR, we calculate, for each replication of the model coefficients, the associated loss function. We then examine the distribution of the loss function under the two rules.

The results are shown in Figure 7. The top chart indicates that in over 75 per cent of all "alternative worlds" that are plausible given the estimate of the DEAM, the DEAMBR does strictly better than the AEAMBR for any combination of the preference parameters. Hence, coefficient variability is not such as to jeopardize our conclusions above. Furthermore, for a large percentage of replications, the reduction of the loss function delivered by the DEAMBR is sizeable.²² Finally, as in the exercise above, we formally test the hypothesis that the average (across replications) welfare loss associated with the DEAMBR is lower than the average loss obtainable with the AEAMBR. The resulting tail

²⁰Each replication includes 800 realizations of the shocks for the six stochastic equations in the model, one realization per period. Only the last 400 simulated values are used to evaluate the objective function, to prevent the results from being biased by the initial conditions.

²¹The test is the standard one-sided test for the equality of the means of normally distributed variables. The 1% critical value is 2.326.

²²See Monteforte and Siviero (2003) for details.

probabilities are shown in the bottom chart of Figure 7: They exceed 70 per cent for all combinations of preference parameters.

We conclude that not only is the welfare loss associated with the AEAMBR large, but it is also statistically significant and robust to parameter uncertainty.

7 Pre-euro data and post-euro modelling, and other robustness checks

The single currency has been in place only for part (though not a negligible part) of the AEAM and DEAM estimation sample. One may thus legitimately question the future validity of results partly relying on pre-euro observations (an issue which of course applies to all euro-area empirical investigations). The short answer to such concern is that our results appear to be valid and reliable for three reasons.

Firstly, the available empirical evidence shows that there is no compelling evidence that heterogeneity of euro area countries has declined in the recent past. Eichengreen (1997) and Demertzis, Hughes Hallett and Rummell (1998), have tackled the issue of the symmetry of the shocks to the European economies, or lack thereof; although the European economies have followed rather similar policies for quite some time, there is little evidence of a strengthening of the degree of symmetry of the disturbances affecting the various economies. More recently, Busetti, Forni, Harvey and Venditti (2006) have shown that the convergence of inflation dynamics in euro countries actually came to a stop and inverted after 1998. Moreover, there is no evidence of a structural break in the monetary policy transmission mechanisms after the introduction of the euro (Clausen and Hayo (2006)).

Secondly, the empirical evidence in Section 2 shows no sign of instability in the estimated parameters of the two models after the introduction of the single currency.

Thirdly, the welfare distance between the AEAMBR and DEAMBR remains virtually the same if we truncate the sample before the introduction of the euro.²³ Increasing the share of post-euro data from zero (with the sample truncated at 1998.Q4) to about one-fourth of the sample (with the sample extending to 2004.Q4) actually strengthens the conclusions.

But what could happen in the far future? There is no reason why convergence should necessarily be assumed to take place.²⁴ Indeed, as mentioned earlier, there is no evidence that much convergence has taken place in the long stretch of time since the start of the run-up to EMU. However, it may be informative to explore how the comparison between the AEAMBR and DEAMBR would be affected in case the heterogeneity of euro area countries' stochastic disturbances gradually vanishes. We thus assume convergence to occur in the stochastic processes that generate the disturbances of the DEAM. Specifically, we assume that, once full convergence is reached, the three countries share the same shocks, which reflect, proportionately to the country's relative size, the (original) country-specific stochastic processes; as in De Grauwe and Piskorski

²³See the results in the mimeo version of this paper, Monteforte and Siviero (2003), where the sample ends in 1998.Q4.

²⁴Hughes Hallett and Piscitelli (2002) show that integration may or may not imply convergence, a key factor in determining the result being the size of the economies involved.

(2001), the common variance is given by the square of a weighted average of the historical estimated standard deviations:

$$\sigma_{y|FC}^2 = (\omega_{y_G} \sigma_{y_G} + \omega_{y_F} \sigma_{y_F} + \omega_{y_I} \sigma_{y_I})^2 \quad (5)$$

where $\sigma_{y|FC}^2$ denotes the variance of the common AD shock under convergence; $\sigma_{y_G}, \sigma_{y_F}, \sigma_{y_I}$ are the estimated standard deviation of AD disturbances in the three countries; $\omega_{y_G}, \omega_{y_F}, \omega_{y_I}$ are the GDP weights of the three countries.

We also consider the possibility of partial convergence, which we assume to be parameterized by ξ_{AD} , ranging from 0 (no convergence) to 1 (full convergence). For any given choice of the ξ_{AD} parameter, the corresponding elements of the variance-covariance matrix of the disturbances are given by:

$$\sigma_{y_i|PC}^2 = \xi_{AD} \sigma_{y|FC}^2 + (1 - \xi_{AD}) \sigma_{y_i}^2 \quad (6)$$

$$\sigma_{y_j y_i|PC} = \xi_{AD} \sigma_{y_i|PC} \sigma_{y_j|PC} \quad (7)$$

for all i, j , so that the correlation of shocks among countries is given by ξ_{AD} itself.²⁵

Full and partial convergence of aggregate supply disturbances are defined in a similar way, with the convergence process now parameterized by ξ_{AS} .

Figure 8 reports, for the case $\lambda = \mu = 1$ (the results are similar for all other values of the policy parameter), the additional welfare loss entailed by adopting the AEAMBR rather than the DEAMBR, as the degree of similarity of supply- and demand-side shocks across countries increases (in the figure, the no-convergence loss found in Section 5 is normalised to 100). With full convergence of shocks, there remains virtually no scope at all for using the DEAMBR. This is no surprise. However, a relatively high degree of (uniform) convergence is needed before the loss associated with using the AEAMBR becomes relatively small. Moreover, if convergence only occurs on the demand side of the economies, then the additional welfare loss associated with the AEAMBR tends to linger rather high.

We further investigated whether our results would be any different if forward-looking AEAMBR and DEAMBR were compared. Following Batini and Haldrup (1999), we require the policy-controlled interest rate to react to model-consistent projections of future area-wide inflation and output gap, with the degree of forward-lookingness varying between 1 and 4. The results deliver the same message as above. With leads larger than 1, the underperformance of the AEAMBR actually tends to be more pronounced than implied by the results in Figure 3.

Finally, we repeated the experiments with a hybrid version of the model.²⁶ With such model, the sub-performance of the AEAMBR is attenuated, but does not necessarily vanish, particularly if the policy-maker attaches no weight

²⁵It would, of course, be possible to introduce the further complication that the speed of convergence is not the same for all countries. For the sake of simplicity we ignore that possibility. Let us just remark that our definition of partial convergence tends to make cross-country heterogeneity disappear more smoothly than it would be possible.

²⁶Specifically, the hybrid model is such that: in the AS, current inflation reacts to both past and future expected inflation; in the AD, the real interest rate is defined as the difference between the nominal interest rate and average expected inflation four quarters ahead. The model was estimated with GMM. Estimation details are available from the authors upon request.

to the volatility of the instrument. Furthermore, as in Adalid, Coenen, McAdam and Siviero (2005), we find that rules computed with backward-looking models are much more robust than the rules based on hybrid models. Hence, risk aversion on the side of the policy-maker should advice to rather rely on the results computed with the backward-looking models used throughout most of this paper.

8 Concluding remarks: What implications for euro area econometric modelling?

Heterogeneity of the economies participating in the euro area is not only statistically detectable but, more importantly, economically relevant, suggesting that euro-area monetary policymaking is likely to be more effective if the econometric tools used to support monetary policy decision-making are disaggregate, rather than aggregate.

The difference in the welfare performance associated to the two competing modelling strategies is sizeable, significant and robust along a number of dimensions, including, among others, the model estimation sample, parameter uncertainty and the timing of the information to which the policy-maker reacts. Only with sizeable convergence (of which there is no sign yet) our conclusions would no longer apply.

Those conclusions are apparent in our simplified model for the three main countries. Arguably they would be all the more supported if individual country models were to pay closer attention to country-specific institutional features, labor market arrangements, tax structures, etc., thereby presumably resulting in a more pronounced degree of heterogeneity across individual country models. Also, should the analysis be extended to cover more countries, this would most likely further accentuate the welfare distance between the AEAMBR and the DEAMBR. Moreover, the odds would turn even more unfavourable to aggregate modelling if models were nonlinear.²⁷ In light of these remarks, it seems legitimate to conjecture that the increase in the welfare losses that we associate to the AEAMBR is likely to provide a lower bound estimate.

All in all, the results make a clear case for relying on a multi-country modelling approach when offering advice in support of the single monetary policy, and suggest that a line of research worth pursuing is a systematic investigation of the aggregation bias (both its size and its nature) in euro-area macroeconomic modelling.

²⁷Hughes Hallett (2000).

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Table 1

ESTIMATE OF THE AEAM

| Input from: | Equation for: | |
|-------------|---|-----------------------|
| | π | y |
| π | 0.610 [-1] (0.077) 0.390 [-4] (restr.) | |
| y | 0.104 [0] (0.038) | 0.809 [-1] (0.054) |
| r | | -.052 [-2] (0.022) |
| R^2 | 0.865 | 0.692 |
| \bar{R}^2 | 0.862 | 0.686 |
| σ | 0.289 | 0.483 |
| DW | 2.283 | 1.868 |

In parentheses: standard error of the coefficients.

In brackets: lag with which the variables enter the equations.

Table 2

ESTIMATE OF THE DEAM

| | | Equations for: Germany | | Equations for: France | | Equations for: Italy | |
|-------------|------------------|--|------------------------|--|------------------------|-----------------------|------------------------|
| Input from: | | π | y | π | y | π | y |
| Germany | π | 0.292 [-1] (0.086) 0.581 [-4] (0.066) | | 0.085 [0] (restr.) | | 0.037 [0] (restr.) | |
| | y | 0.091 [-1] (0.033) | 0.770 [-1] (0.058) | | | | 0.113 [0] (0.067) |
| | r | | -0.076 [-2] (0.034) | | | | |
| France | π | 0.127 [0] (restr.) | | 0.915 [-1] (0.049) | | | |
| | y | | | 0.021 [-2] (0.010) 0.021 [-3] (0.010) 0.021 [-4] (0.010) 0.021 [-5] (0.010) | 0.864 [-1] (0.047) | | |
| | | | | | | | |
| | r | | | | -0.043 [-2] (0.014) | | |
| Italy | π | | | | | 0.963 [-1] (0.010) | |
| | y | | | | | 0.065 [0] (0.027) | 0.697 [-1] (0.065) |
| | r | | | | | | -0.035 [-1] (0.014) |
| | R^2 | 0.494 | 0.640 | 0.890 | 0.777 | 0.960 | 0.735 |
| | \overline{R}^2 | 0.470 | 0.630 | 0.884 | 0.762 | 0.957 | 0.724 |
| | σ | 0.393 | 0.730 | 0.335 | 0.412 | 0.261 | 0.470 |
| | DW | 2.298 | 1.938 | 2.251 | 1.970 | 2.186 | 1.916 |

In parentheses: standard error of the coefficients.
In brackets: lag with which the variables enter the equations.

Table 3

OUT OF SAMPLE STABILITY, AEAM, 1998.Q1-2004.Q4

| Equation | F-value | Tail probability |
|----------|---------|------------------|
| AS | 0.91 | 56.59 |
| AD | 0.68 | 82.98 |

Table 4

OUT OF SAMPLE STABILITY, DEAM, 1998.Q1-2004.Q4

| Equation | | F-value | Tail probability |
|----------|----|---------|------------------|
| Germany | AS | 0.79 | 70.74 |
| | AD | 0.51 | 99.23 |
| France | AS | 1.13 | 34.13 |
| | AD | 1.65 | 6.34 |
| Italy | AS | 1.30 | 20.05 |
| | AD | 0.58 | 91.35 |

Table 5

AGGREGATION CRITERIA

| | <i>DEAM</i> | <i>AEAM</i> |
|------------------|-------------|-------------|
| AGGREGATE SUPPLY | | |
| GG criterium | 3.856 | 9.791 |
| PPK criterium | 0.225 | 0.289 |
| | | |
| AGGREGATE DEMAND | | |
| GG criterium | 15.948 | 24.461 |
| PPK criterium | 0.449 | 0.482 |

GG : Grunfeld and Griliches (1960)
PPK: Pesaran, Pierse and Kumar (1989).

Table 6

RMSE OF N-STEP AHEAD ERRORS
(1998:1 2004:4)

| DEAM | Aggregate supply | Aggregate demand |
|------|------------------|------------------|
| 1 | 0.226 | 0.328 |
| 2 | 0.228 | 0.524 |
| 3 | 0.222 | 0.662 |
| 4 | 0.249 | 0.747 |
| 5 | 0.268 | 0.771 |
| 6 | 0.258 | 0.780 |
| 7 | 0.261 | 0.774 |
| 8 | 0.268 | 0.804 |

| AEAM | Aggregate supply | Aggregate demand |
|------|------------------|------------------|
| 1 | 0.237 | 0.340 |
| 2 | 0.242 | 0.560 |
| 3 | 0.241 | 0.719 |
| 4 | 0.261 | 0.808 |
| 5 | 0.277 | 0.845 |
| 6 | 0.275 | 0.866 |
| 7 | 0.298 | 0.878 |
| 8 | 0.305 | 0.916 |

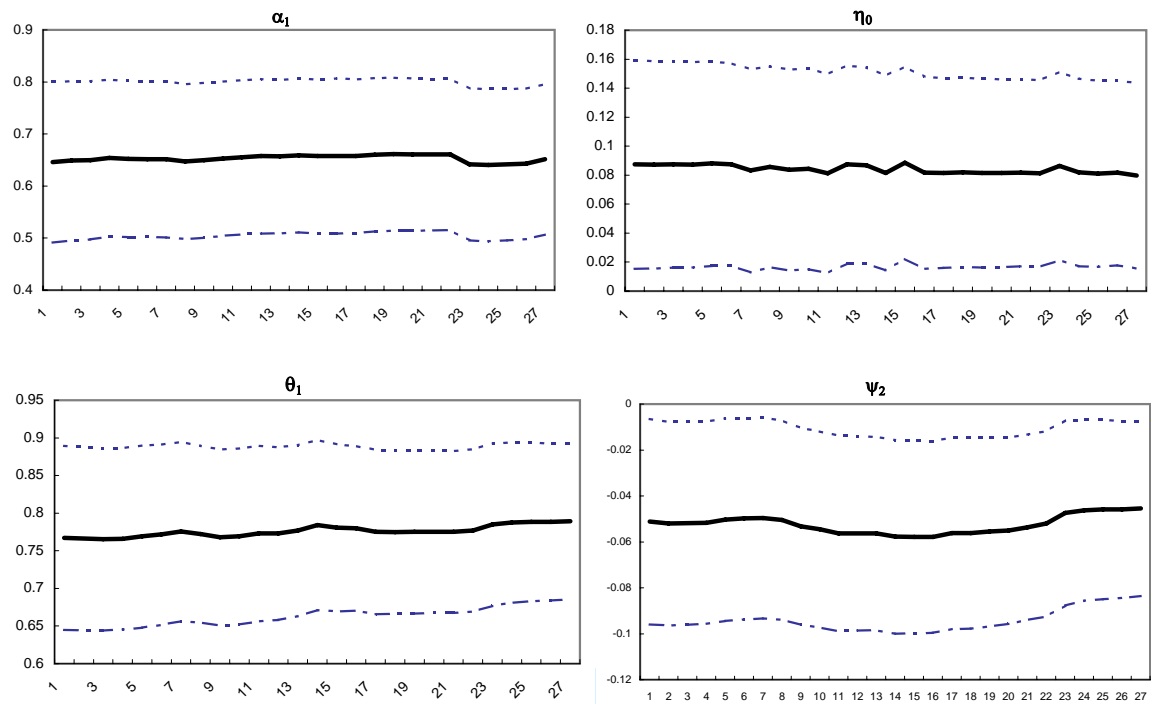
Table 7

Reaction function coefficients and loss values for the AEAMBR and the DEAMBR

| Parameter values in the loss function: | | Type of rule | Coefficients on: | | | Standard deviation of: | | Loss |
|---|-----------|--------------|-------------------------|------------|-------------------------|-------------------------|------------|-------|
| | | | Annualised Inflation | Output gap | Lagged interest rate | Annualised Inflation | Output gap | |
| $\lambda = 0.1$ | $\mu=0.1$ | DEAMBR | 2.27 | 1.86 | 0.71 | 2.12 | 1.55 | 5.96 |
| | | AEAMBR | 1.56 | 1.39 | 0.72 | 2.44 | 1.36 | 6.69 |
| | $\mu=1$ | DEAMBR | 0.91 | 0.94 | 0.84 | 2.70 | 1.43 | 10.26 |
| | | AEAMBR | 0.67 | 0.71 | 0.83 | 3.25 | 1.26 | 12.08 |
| $\lambda = 1$ | $\mu=0.1$ | DEAMBR | 2.33 | 2.08 | 0.67 | 2.19 | 1.39 | 7.89 |
| | | AEAMBR | 1.56 | 1.58 | 0.67 | 2.66 | 1.22 | 9.08 |
| | $\mu=1$ | DEAMBR | 0.94 | 0.99 | 0.82 | 2.73 | 1.36 | 12.01 |
| | | AEAMBR | 0.67 | 0.76 | 0.81 | 3.43 | 1.20 | 14.49 |
| $\lambda = 2$ | $\mu=0.1$ | DEAMBR | 2.38 | 2.28 | 0.63 | 2.27 | 1.31 | 9.70 |
| | | AEAMBR | 1.57 | 1.75 | 0.63 | 2.89 | 1.15 | 11.46 |
| | $\mu=1$ | DEAMBR | 0.97 | 1.05 | 0.81 | 2.76 | 1.32 | 13.80 |
| | | AEAMBR | 0.68 | 0.81 | 0.80 | 3.62 | 1.16 | 17.02 |

Figure 1

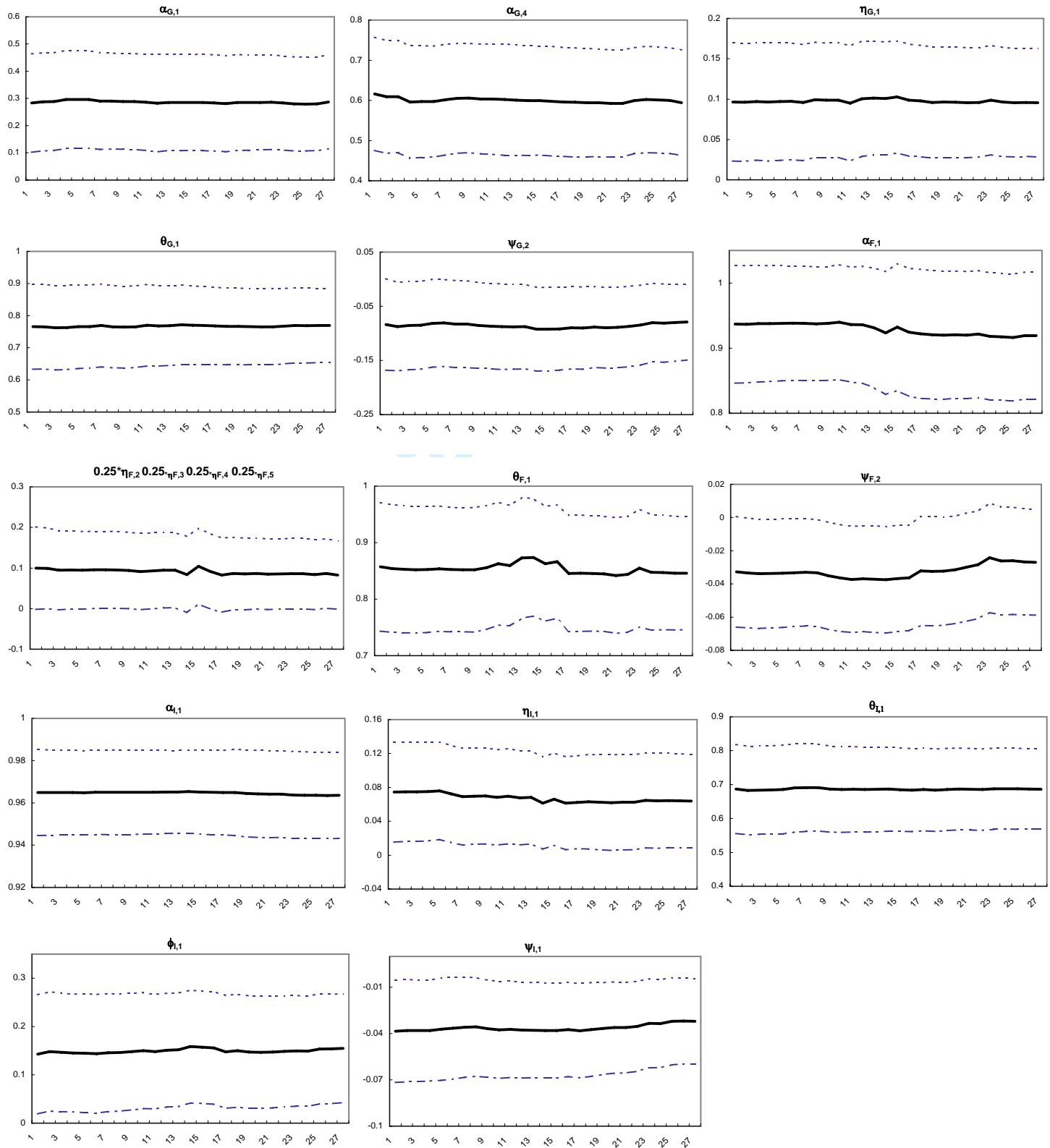
RECURSIVE ESTIMATES OF AEAM COEFFICIENTS, 1998.Q1 – 2004.Q4



Note: For parameter definitions, see eq. (1) in the text.

Figure 2

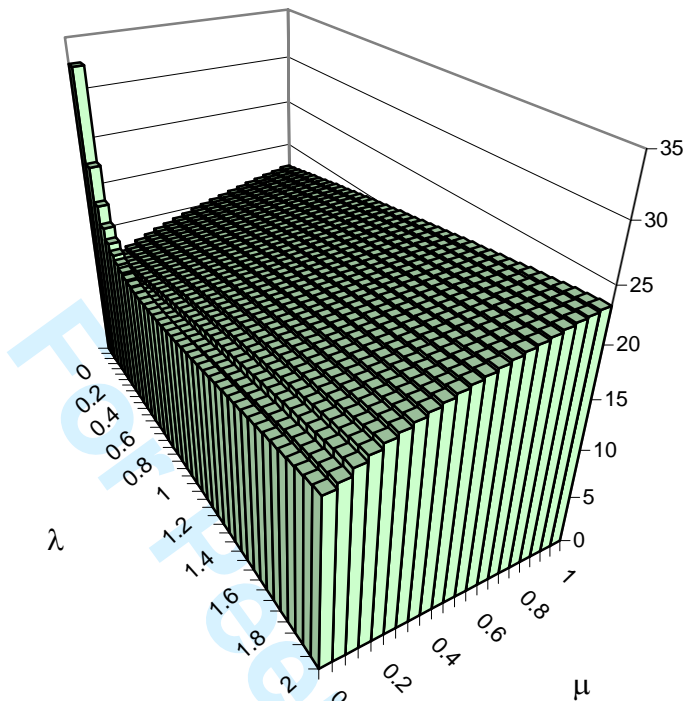
RECURSIVE ESTIMATES OF DEAM COEFFICIENTS, 1998.Q1 – 2004.Q4



Note: For parameter definitions, see eq. (2) in the text.

Figure 3

Percentage additional loss, AEAM-based rule vs. DEAM-based rule



Percentage additional loss, AEAM-based rule vs. DEAM-based rule
(as a share of the additional loss with the DEAM-based rule vs. the loss with the FO rule)

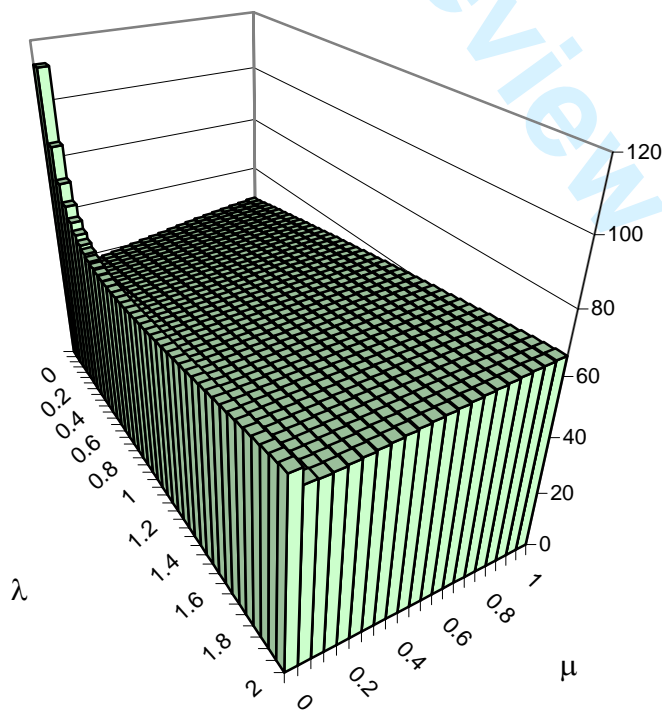


Figure 4

Inflation - output gap optimal frontiers

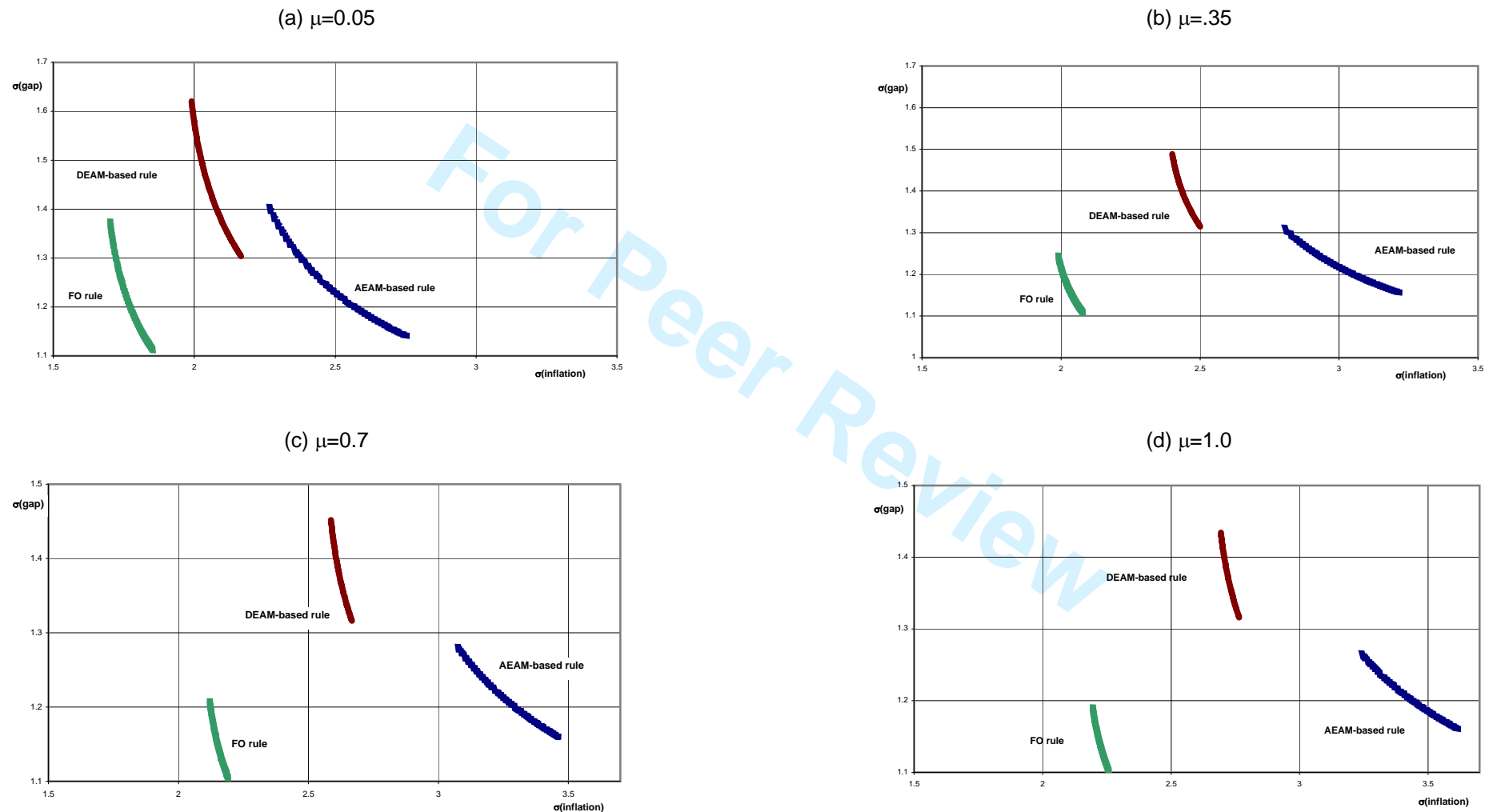
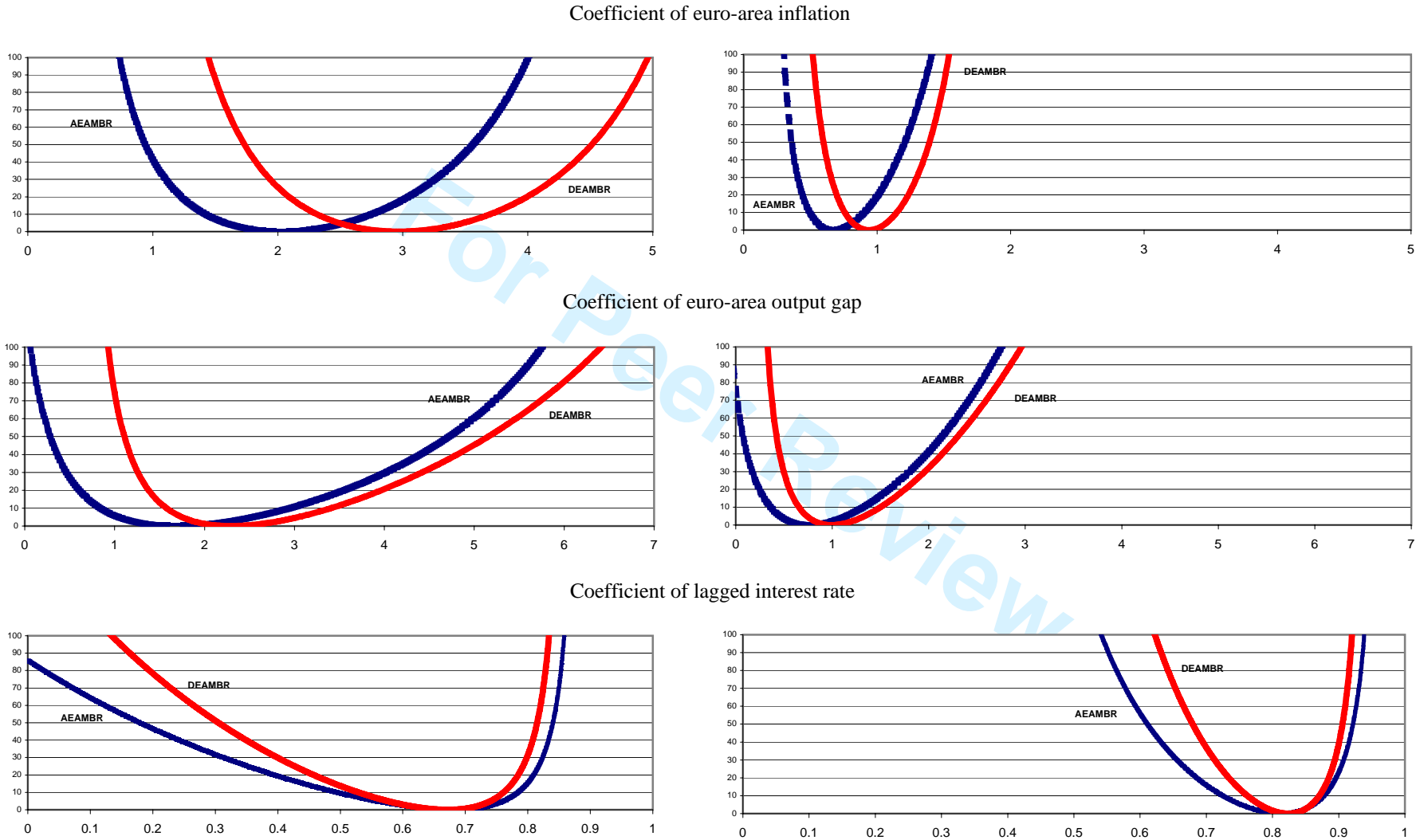


Figure 5

Fault tolerances of AEAMBR and DEAMBR

$\lambda=0.05, \mu=0.05$

$\lambda=1, \mu=1$

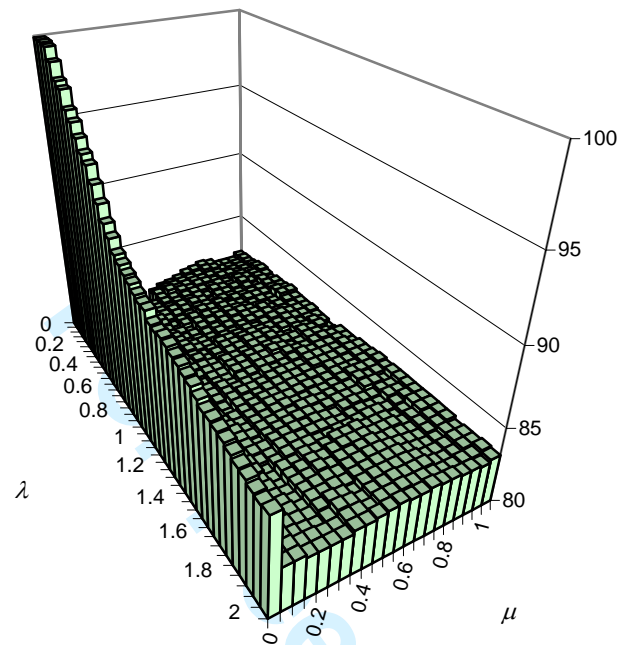


Note: Each curve shows the percentage increase in the loss function when the rule coefficients are moved away from their optimised values (corresponding to the points of minimum of each curve).

Figure 6

Random drawing from distribution of estimated DEAM residuals, DEAMBR vs. AEAMBR

Percentage of cases in which the DEAMBR outperforms the AEAMBR



Random drawings from distribution of estimated DEAM residuals DEAMBR vs. AEAMBR

Testing the significance of the underperformance of the AEAMBR

(value of the test; 1% critical value: 2.326)

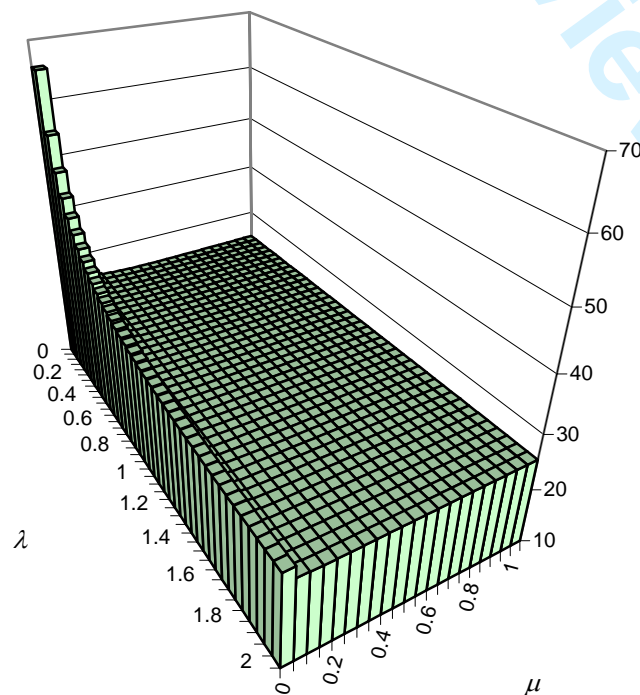
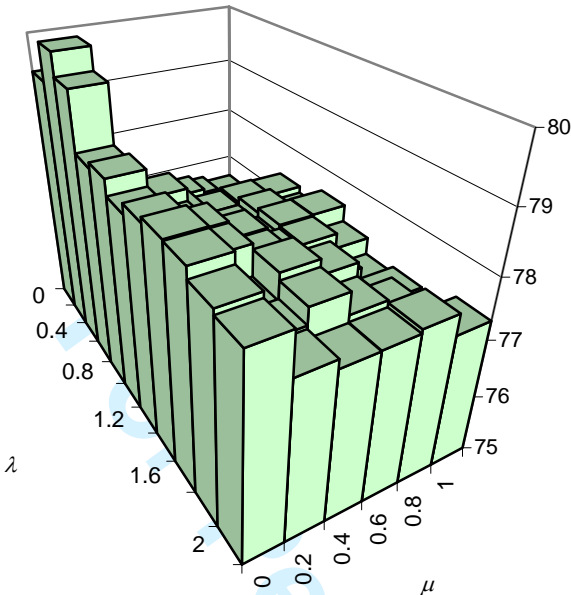


Figure 7

Random drawings from distribution of estimated DEAM parameters,
DEAMBR vs. AEAMBR

Percentage of cases in which the DEAMBR outperforms the AEAMBR



Random drawings from distribution of estimated DEAM parameters,
DEAMBR vs. AEAMBR

Testing the significance of the underperformance of the AEAMBR
(tail probability)

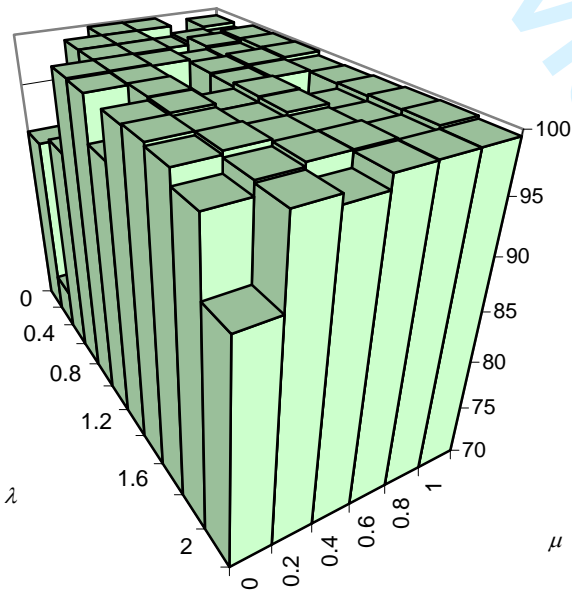


Figure 8

Effects of convergence of stochastic shocks on the AEAMBR/DEAMBR comparison

(Additional welfare loss, AEAMBR vs. DEAMBR; with gradual convergence of the stochastic processes of AD and AS equations; $\lambda=\mu=1$; the result for the case of no convergence is set = 100)

